Will the introduction of nutrient benchmarks help to achieve sustainable milk production systems?

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Abstract

There has been a dramatic expansion of dairying in New Zealand in the last two decades. This has been accompanied by a series of environmental issues around water use and water pollution. This thesis looks at the issue of excess nitrogen and phosphorus lost off dairy farms to waterways using a mixed method approach. Qualitative interviews with dairy farmers and GIS based water quality modelling are employed to explore whether the introduction of nutrient benchmarks would achieve sustainable milk production systems. Two Best Practice Dairy Catchments, Waikakahi in South Canterbury and Inchbonnie on the West Coast, were investigated as the study areas. These catchments are part of an established DairyNZ program. Findings show that nutrient benchmarks do have the ability to achieve sustainable milk production systems in the catchments. It presents the implications and recommendations for the benchmarking project.

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Acknowledgements

I began this thesis three days before the commencement of the series of earthquake that changed the face of Christchurch. I could not write this without acknowledging the great Cantabrian spirit that has endured over 10,000 earthquakes. We may have lost many things in these earthquakes but I am confident we have the ability to rebuild our city physically and emotionally. Kia kaha.

The journey to complete this thesis has been made easier by the encouragement, support and guidance of numerous people. I would like to take this opportunity to acknowledge their help as without it this thesis would not have been successfully completed.

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Chapter 1 INTRODUCTION

1.1 Thesis statement

The dairy industry is New Zealand's largest export earner. In the year ended June 2011 dairy products accounted for 27% of New Zealand's total merchandise exports (Statistics New Zealand, 2011). The growth of the dairy industry is a result of rapid intensification and expansion in the last couple of decades. Figure 1.1 illustrates how the total number of dairy cows in New Zealand began to increase in the 1980's along with the total effective hectares of land used for dairy. This intensification is a result of expansion into areas that were previously not dairy land as well as intensification of milk production on existing farms. Figure 1.2 illustrates how dairying in the South Island, particularly in Canterbury and Southland has expanded in the last decade. While 65% of the 4.5 million dairy cows are still in the North Island, dairying in the South Island looks set to continue growing (DairyNZ, 2010a; O'Keefe, 2010).

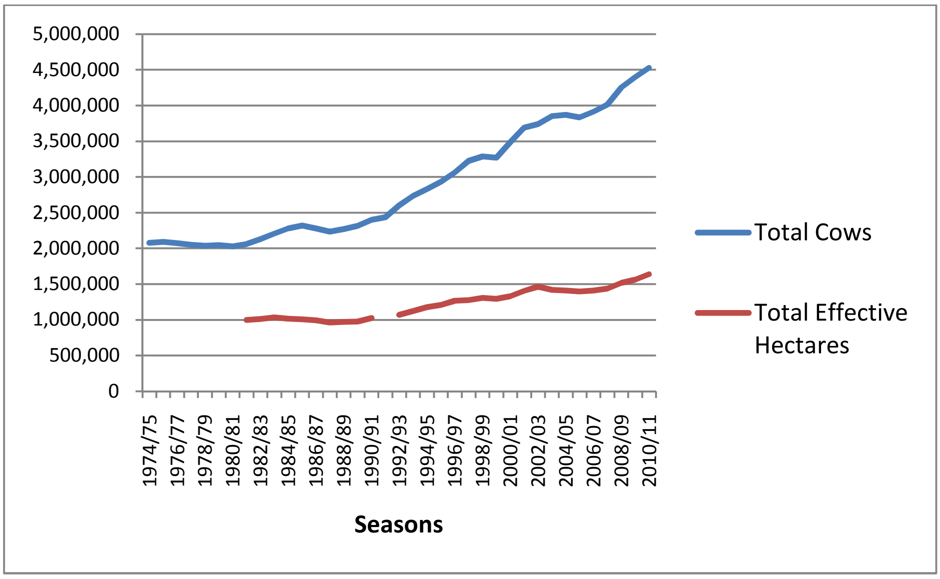

Figure 1.1. Increase in dairy cow numbers and effective hectares used for dairying in New Zealand since 1974. Adapted from "New Zealand Dairy Statistics 2010-11" by DairyNZ & Livestock Improvement Corporation, 2011, Table 2.2, p.7

The New Zealand economy has benefitted from the expansion of dairy. It has been noted that export revenue from the dairy sector helped raise the New Zealand economy during the recent global recession (DairyNZ, 2010a). However there are also increased concerns about the environmental consequences associated with dairying: particularly around water quality and quantity. Managing these consequences effectively is a key environmental focus for both the New Zealand public and the dairy industry because of the importance of the water resource. “Water is one of New Zealand’s major national advantages. It underpins much of our economic development and growth, is part of our heritage and identity, is a means of pleasure and recreation, and supports our unique ecosystems. Water sustains human, plant and animal life. It is essential to the food that we eat.” (Land and Water Forum, 2010, p. 7).

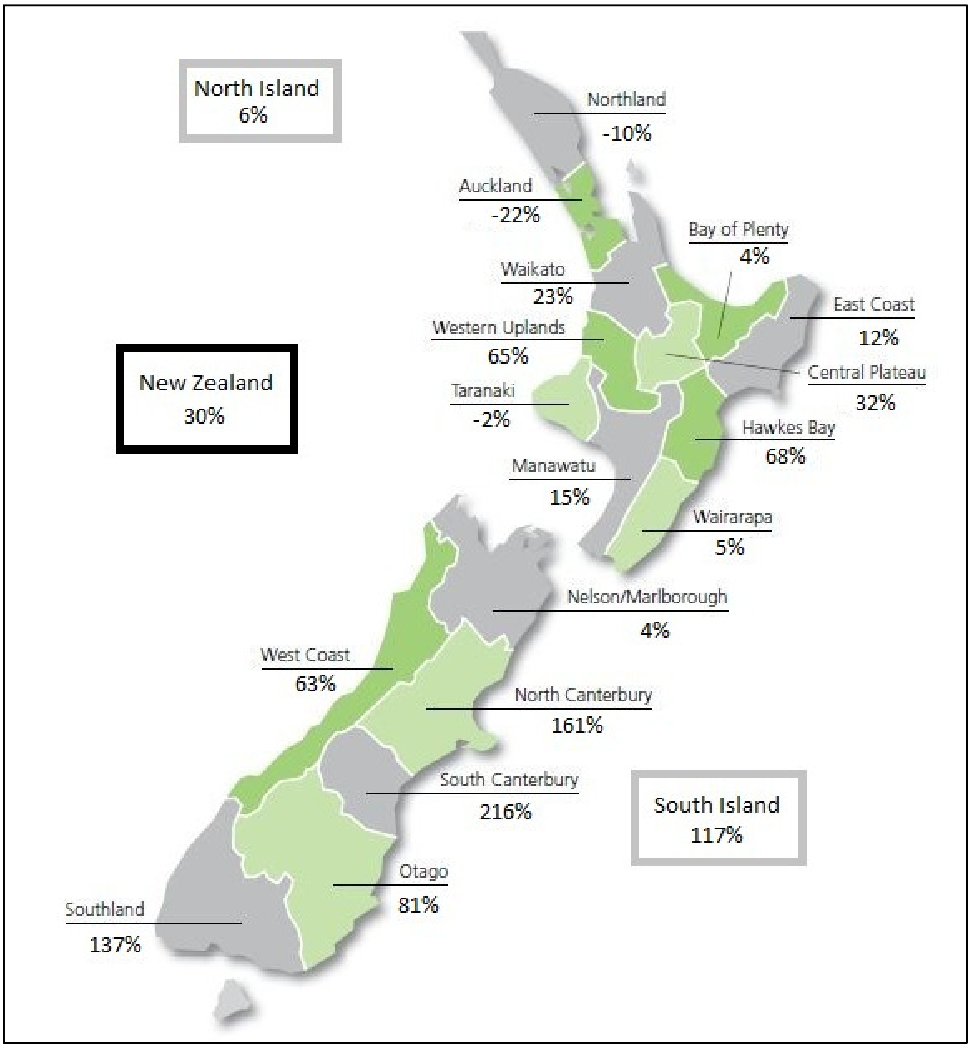

Figure 1.2. The regional percentage change in total cow numbers between 2000 and 2011. Adapted from “New Zealand Dairy Statistics 2010-11” by DairyNZ & Livestock Improvement Corporation, 2011, Table 2.2, p.7.

New Zealand's pasture based dairy farms contribute significantly to degraded groundwater and surface water quality through the loss of nutrients, bacteria and sediment. The main nutrients of concern are nitrogen (N) and phosphorus (P). These nutrients are sourced from fertiliser, soil or animal wastes and are transported by overland run-off, subsurface flow or point source discharge into water bodies. Excessive amounts of these nutrients in water bodies causes eutrophication which impacts on stream ecology and affects cultural, recreational and amenity values (Smith et al., 1999; Thomas & Tracey, 2005; Wilcock et al., 1999). The introduction of efficient nutrient management is required to reduce the environmental impact of dairying while allowing productivity to continue to grow in New Zealand.

The recent approach to managing the environmental impact from dairying by industry and governmental regulation has focussed on reducing the loss of nutrients to water ways from point source discharge in New Zealand, as well as managing fertiliser use. Point source discharge occurs when contaminants are released to waterways from a single identifiable point, like a pipe. It has thus far been ineffective at managing nutrients from diffuse sources which do not emanate from a single point but are spread over a large area or are from an unquantifiable source. This is likely to be due to both the speed of changes that have occurred and the focus on the more obvious point source discharges. Improving nutrient management on farms is emerging as the key to managing diffuse nutrient sources. Recent changes in the management of Lake Taupo and Lake Rotorua by Environment Waikato and Environment Bay of Plenty respectively are promising examples of this. The regional councils have implemented changes that cap nutrient loads into the lakes to prevent further degradation of the water quality. Individual farms in the catchments are allocated a portion of this nutrient cap and have to improve nutrient management on farm to stay within this allocation.

DairyNZ is an industry good organisation whose role is to work in the interest of New Zealand dairy farmers to enhance their profitability, sustainability and competitiveness. It is funded through a combination of a milk solids levy from all dairy farmers and government investment (DairyNZ, 2009a). DairyNZ has taken responsibility for the development of a self management approach to reduce the nutrient footprint from dairying while still maximising production. Increasing efficient use of nutrients is one of the key strategies to achieve this. DairyNZ is focusing on establishing nutrient benchmarks to provide dairy farmers with a target for good nutrient management in their region. The nutrient benchmarks are specific nutrient targets developed using values from farms in the catchment or region. The nutrient benchmarks are based around three indicators: N conversion efficiency which is a calculation of how much external N inputs are converted into N contained in products; N leaching loss which is an estimation of the amount of nitrogen leached and lost from the farm through soil and drainage water below the plant root system and P run-off which is an estimation of the amount of P lost from the farm via surface run-off. The benchmarks will help farmers achieve nutrient management on farm that is appropriate for their catchment.

1.2 Best Practice Dairy Catchments

Introducing nutrient benchmarks nationwide is a new approach for the New Zealand dairy industry. The benchmark concept will be trialled in two of the Best Practice Dairy Catchments (BPDC) before being launched nationally. The BPDC project began in 2001 and was instigated due to concerns about degradation of soil and water quality and the impact this would have on the long-term sustainability of dairy farming (Hayward, 2010). The BPDC project is a collaboration between research institutes, regional councils and industry agencies: mainly Fonterra, DairyNZ, AgResearch and NIWA (Hayward, 2010; Mackay & Smith, 2010). The primary objective of the project is “to integrate practice that protects the environment into dairy farming, against a background of intensification, dairy industry environmental and animal welfare guidelines and the industry policy to increase productivity by 4% per annum” (Russell et al., 2006, p. 2).

Five (initially four) contrasting catchments, each representative of its particular region, were chosen to be part of the BPDC project. The four original catchments were Toenepi in Waikato, Waiokura in South Taranaki, Waikakahi in South Canterbury and Bog Burn in Western Southland as shown in Figure 1.3. Inchbonnie on the West Coast was included in 2004 (Mackay & Smith, 2010; Parshotam & Elliott, 2009; Russell et al., 2006).

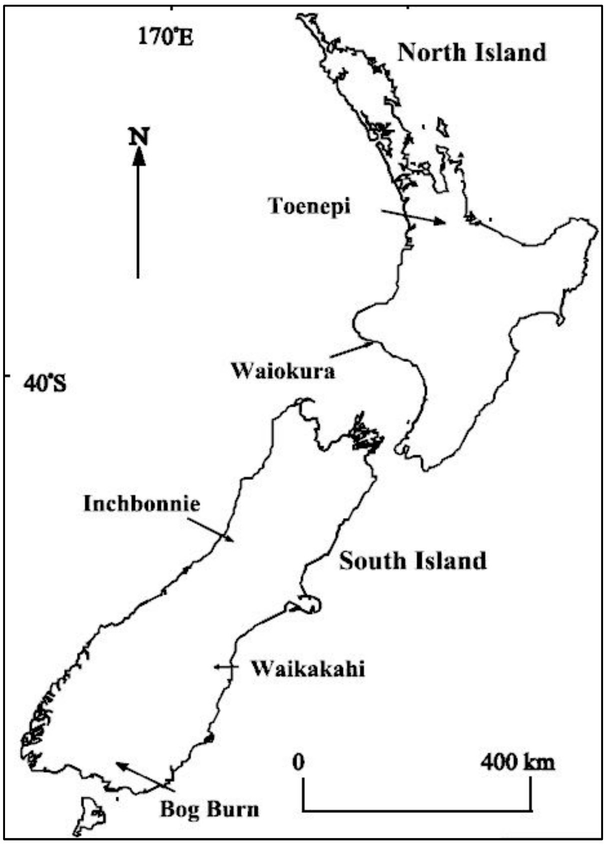

Figure 1.3. Location of the original five Best Practice Dairy Catchments. From "Land-water interactions in five contrasting dairy catchments: issues and solutions" by Wilcock et al., 2007, Land and Water Resources Research, 7, p. 2.2.

The Pastoral 21 Environmental Program has been the primary funder for research efforts in the BPDC project, while Ministry of Agriculture and Forestry's Sustainable Farming Fund (SFF) supported the development of farmer engagement and adoption processes (Monaghan et al., 2009b; Scarsbrook, 2011a). Pastoral 21 is a joint investment by DairyNZ, Fonterra, Beef + Lamb New Zealand and the Ministry of Science and Innovation. It was created in 2007 to increase farm productivity and lessen environmental impacts. This was achieved by funding research projects as well as projects that encourage farmers to adopt production and environmental improvements (AgResearch, 2011). The SFF is led by Ministry of Agriculture and Forestry (MAF) it funds research or extension projects to provide environment, economic or social benefits to primary land industries in New Zealand (Ministry of Agriculture and Forestry, 2011). The Pastoral 21 funding for the BPDC ended in February 2011. This meant the majority of resources to continue research, monitoring, consultation and extension work also ended. As a result of the funding changes the entire BPDC program has been reviewed (Scarsbrook, 2011a). Currently BPDC project activity is only continuing in the Waikakahi and Inchbonnie catchments (Monaghan et al., 2009b; Scarsbrook, 2011a).

1.3 Research aim

The main aim of this research is to determine if the nutrient benchmarks will help achieve sustainable milk production systems. This aim is achieved through the analysis of the following questions:

- What is meant by sustainable milk production systems?
- How do dairy farmers in the two Best Practice Dairy Catchments interpret the benchmarks?
- How effective are benchmarks in managing nutrient loss and improving water quality in the two Best Practice Dairy Catchments?

The focus will be on the two active BPDC. They are the obvious choice because the development of nutrient benchmarks is being piloted in these catchments. A mixed method approach is taken in order to achieve the main aim. It includes the use of qualitative telephone interviews and quantitative catchment-scale water quality modelling. The modelling will be undertaken using CLUES (Catchment Land Use for Environmental Sustainability) which works within a Geographic Information Systems (GIS) platform. CLUES was developed to model the impact of changes in land use on water quality in the New Zealand environment. It has been employed in this research due to its established use for catchment-scale exploration of land use changes in water quality (Lilburne et al., 2011; Monaghan et al., 2010). CLUES is a publically available GIS based model. It has been applied in several New Zealand catchments to identify contaminant inputs from certain land uses and critical source areas. It is also used to ascertain the effect of land use changes and mitigation measures on the volume of contaminant inputs (Elliott et al., 2011).

Through the BPDC project a professional relationship has developed between DairyNZ and the dairy farmers in the catchments. There is an established network of farmers who are familiar with farm surveys. This is critical to the successful uptake of the interviews as the researcher is able to be introduced to the farmers. In addition baseline water quality, flow and farm system monitoring has been undertaken in these catchments as part of the BPDC project (Hayward, 2010). This made them ideal catchments in which to model water quality as predicted results can be compared to current measurements. There is limited combined water quality, flow and land use monitoring data in New Zealand that exists at a meaningful temporal and spatial scale. The BPDC are some of the few catchments where regular comprehensive monitoring occurs. As well as having access to the existing data the two catchments make good study areas because of their contrasting physical and social characteristics which will be explored in the following section. This contrast provides the ability for a more robust analysis of benchmark implementation.

1.4 Study areas

Table 1.1 describes the main stakeholders in the Inchbonnie and Waikakahi catchments. It is not an exclusive list but includes those who are directly involved in nutrient management or the nutrient benchmark project. It identifies their roles in the catchments and provides the social context of the study areas. It also gives the average physical characteristics of the dairy farms which provide a background to the study areas referred to in this section.

Table 1.1. Main stakeholders in the Inchbonnie and Waikakahi catchments who are referred to in this research

	Inchbonnie	**Waikakahi**
Dairy Farmers	• Five dairy farms • Average farm size 120 hectares • Average herd size 425 cows (Ministry for the Environment, 2009)	• Thirteen dairy farms • Average farm size 231 hectares • Average herd size 665 cows (Ministry for the Environment, 2009)
Milk Producers Collect milk from farms, process, market and distribute it national and internationally	**Westland Milk Products** • 386 Suppliers • 45.7 million kg of milk solids in 2010 season (Westland Milk Products, 2010)	**Fonterra** • 10,500 suppliers • 96% NZ's total suppliers • 1286 million kg of milk solids in 2010 season (Fonterra, 2010b, 2011c)
Regional Councils Responsible for the management of natural and physical resources in the region. Preparation of plans to manage the development and use of resources that protect, avoid or mitigate harmful use of natural resources	**West Coast Regional Council** • Based in Greymouth • Has a proposed Regional Land and Water plan which is operative in the Inchbonnie catchment • Several rules specifically relate to dairy farms and Lake Brunner (West Coast Regional Council, 2010)	**Environment Canterbury** • Based in Christchurch and Lincoln (post earthquake) • Has an operative Canterbury Natural Resources Regional Plan • Rules for discharges to waterways and discharge of farm dairy effluent • Failure to adequately address water quality and water quantity issues led to the appointment of commissioners to run Environment Canterbury in 2010 as opposed to elected council. (Environment Canterbury, 2010a)
Fertiliser Agents Supply fertiliser products as well as technical advice and soil testing related to fertiliser. Fertiliser representatives in each region are responsible for making nutrient budgets for each farm. Individual farms decide what fertiliser agency they will patronage.	• Ravensdown, • Balance • Altum (Summit-Quinphos) • Mainland Minerals	• Ravensdown, • Balance • Altum (Summit-Quinphos) • Mainland Minerals

1.4.1 The Inchbonnie Catchment

Site description

The Inchbonnie Catchment lies to the south of Lake Brunner on the West Coast of the South Island of New Zealand illustrated in Figure 1.4. Pigeon Creek is the major waterway of the catchment. It is fed by a spring towards the southern end of the catchment as well as drainage off the land. It runs across a flat slope draining a 6 km^2 area used exclusively for dairy farming (Ministry for the Environment, 2009). Pigeon Creek flows into Bruce Creek, shown in orange in Figure 1.4. Bruce Creek is a tributary of the Orangipuku River and is shown in red in Figure 1.4, which then discharges to Lake Brunner (Monaghan et al., 2007b; Wilcock et al., 2007). The Inchbonnie Catchment receives on average 4800 mm/yr of rain, making it one of the wettest dairy farming areas in New Zealand (Ministry for the Environment, 2009). This rainfall is not constant but occurs in intense storm events which dominate the hydrology of the catchment causing high flow floods. These floods create significant surface run-off flush the creeks. Flows of up to 12,600L/s have been recorded (Chague-Goff et al., 2009; Wilcock & Duncan, 2009).

The primary reason Inchbonnie was included in the BPDC is because it is a tributary of Lake Brunner. Lake Brunner is the largest lake in the West Coast region. It is situated 30 km inland from Greymouth (Horrox, 2008; McDowell, 2010). The lake is fed predominantly by the Crooked, Orangipuku and Hohonu Rivers and discharged via the Arnold River to the north as illustrated in Figure 1.4. Lake Brunner is of importance to a wide range of groups and is a special management area in the West Coast Regional Council's Proposed Land and Water Plan (PLWP) (2010). Inchbonnie is one of two main dairy farming areas in the wider Lake Brunner catchment, the other is the Crooked River catchment. They have an impact on the water quality of the lake by contributing to nutrient loadings (Wilcock & Duncan, 2009; Wilcock et al., 2007). The average total P load of 5 kgP/ha/yr in Pigeon Creek is notably higher than loads in other monitored dairy catchments which range between 0.3-1.2 kgP/ha/yr (Wilcock & Duncan, 2009)

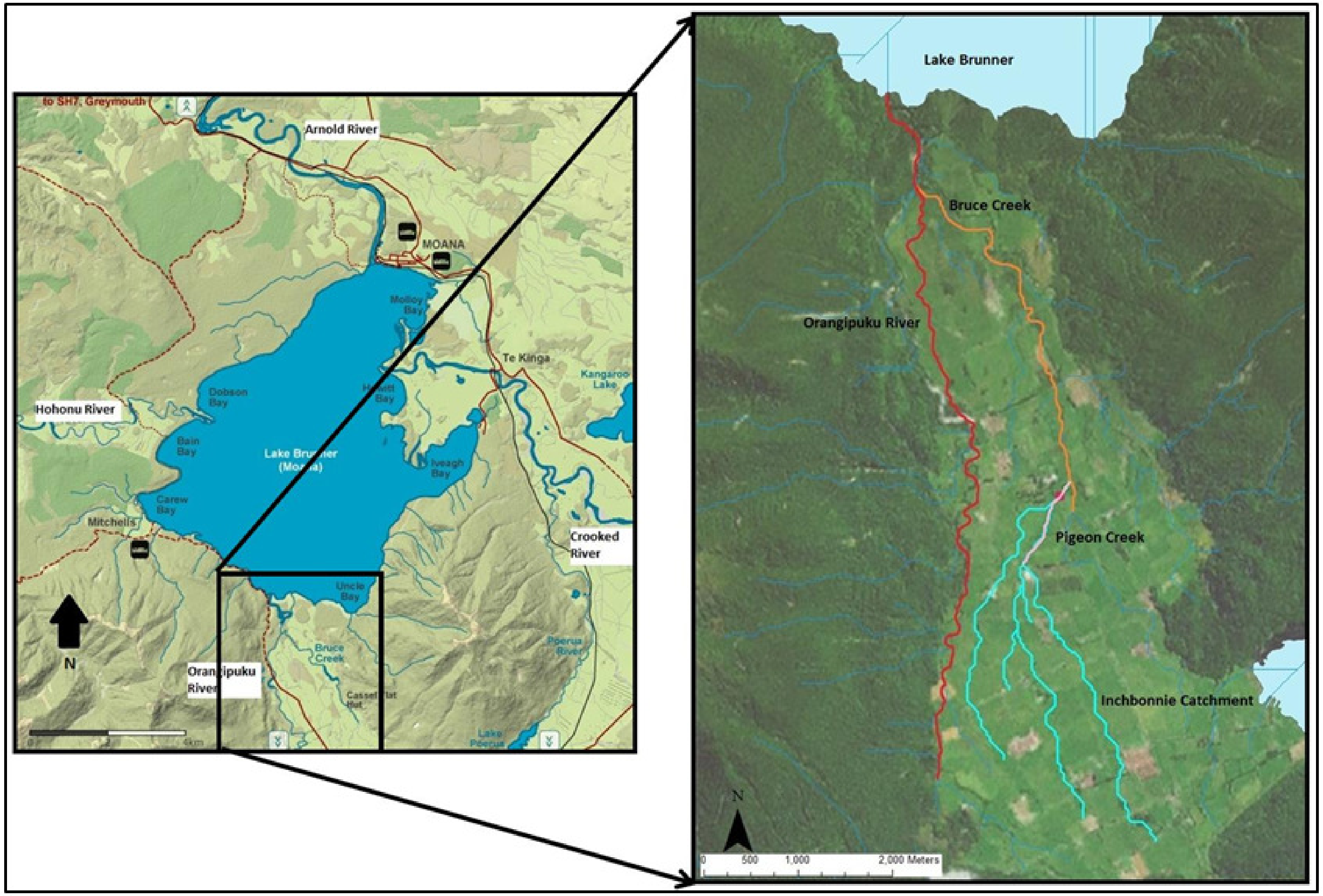

Figure 1.4. Location maps showing the Lake Brunner catchment, on the left, with its three main tributaries as well as discharge via the Arnold River. On the right the location map of Pigeon Creek and the Inchbonnie catchment. Adapted from NZ "Lake Brunner Map" by NZFishing, n.d., http://www.nzfishing.com/FishingWaters/West%20Coast/WCMaps/Lake_BrunnerTopo.htm

There is growing public concern over the water quality of Lake Brunner (Wilcock et al., 2007). Lake Brunner is currently in an oligotrophic state which means it has low nutrient levels and correspondingly low algal growth. Phosphorus (P) is considered to be the nutrient that is limiting algal growth in the lake (Bramley, 2009; Horrox, 2008; Horrox et al., 2011; McDowell, 2010; Wilcock & Duncan, 2009; Wilcock et al., 2007). The management of P loss is the main concern in the wider Lake Brunner catchment and therefore will be the focus of the benchmarking project in the Inchbonnie Catchment. Nitrogen (N) concentrations in the lake have stabilised with no significant changes in the last 10 years (Horrox et al., 2011; McDowell, 2010).

Main environmental concerns regarding Lake Brunner

The high annual rainfall in the Inchbonnie catchment creates unique challenges for nutrient management on dairy farms. Hari Hari silt loam, the predominant soil type in the Inchbonnie catchment, has low P retention due to low volumes of aluminium and iron oxides which bind P to soil (McDowell, 2008; Monaghan et al., 2007b; Thomas & Tracey, 2005). This low P retention combined with high annual rainfall means there is greater potential for P to reach the lake than if the soil was similar to those in other dairying catchments in New Zealand (Horrox, 2008). Fertiliser is estimated to contribute to between 10 and 40% of total P loss in the Lake Brunner catchment (McDowell, 2010). The risk of P loss from fertiliser is high in this catchment because of the high annual rainfall (Chague-Goff et al., 2009; Chague-Goff et al., 2006; McDowell, 2010).

Humping and hollowing, a form of land contouring, is commonly used on the West Coast to assist land drainage. It creates farmable dry land in areas that could not otherwise be farmed (McDowell, 2008; West Coast Regional Council, 2008). Figure 1.5 illustrates a humped and hollowed pasture. Hollows are formed 10-20 m apart, the humps sit 1-2 m higher than the hollows (Blackett et al., 2005; McDowell, 2010). Water runs off the top of the humps into the free draining soil in the hollows. From there it seeps into groundwater or into surface water via drains. Humping and hollowing provides an excellent conduit for nutrients from fertiliser or stock excreta to run straight into surface water. Directing water flow off the humps into hollows also decreases the chance for attenuation in the plant root zone (McDowell, 2010). This has a negative impact on water quality and because of this the practice has a poor public perception (Chague-Goff et al., 2009). The already high risk of P loss due to heavy rainfall in the catchment is intensified by humping and hollowing.

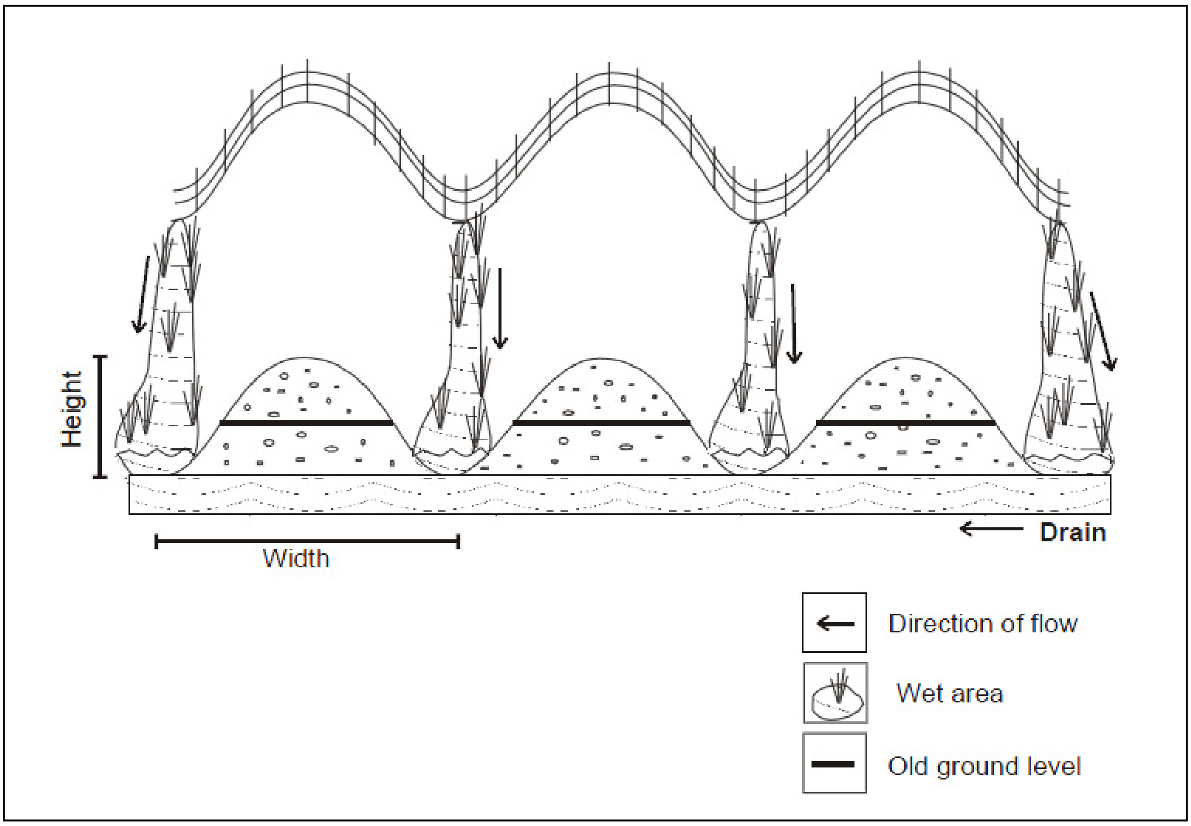

Figure 1.5. A three-dimensional diagram of a humped and hollowed pasture showing a perpendicular cross section of the paddock. From "Humps and hollows on West Coast dairy farms: farmer management practices and responses to nutrient runoff solutions" by Blackett et al., 2005, NIWA Client Report: CHC2005-062. p. 6.

1.4.2 The Waikakahi Catchment

Site description

The Waikakahi catchment is located in South Canterbury and is an example of a typical Canterbury lowland catchment. The Waikakahi Stream, which is the main waterway, originates from springs in the base of the hills plus some run-off from the hills and flows across the Glenavy-Ikawai Plains (Meredith et al., 2003). Figure 1.6 illustrates how the Waikakahi Stream flows east across intensive farmland and discharges into the Waitaki River upstream from State Highway 1 (Meredith et al., 2003). The flat land is dominated by the thirteen dairy farms which account for 90% of its total land use. The hill areas are used for beef and wool dry stock (Monaghan et al., 2009a; Monaghan et al., 2009b).

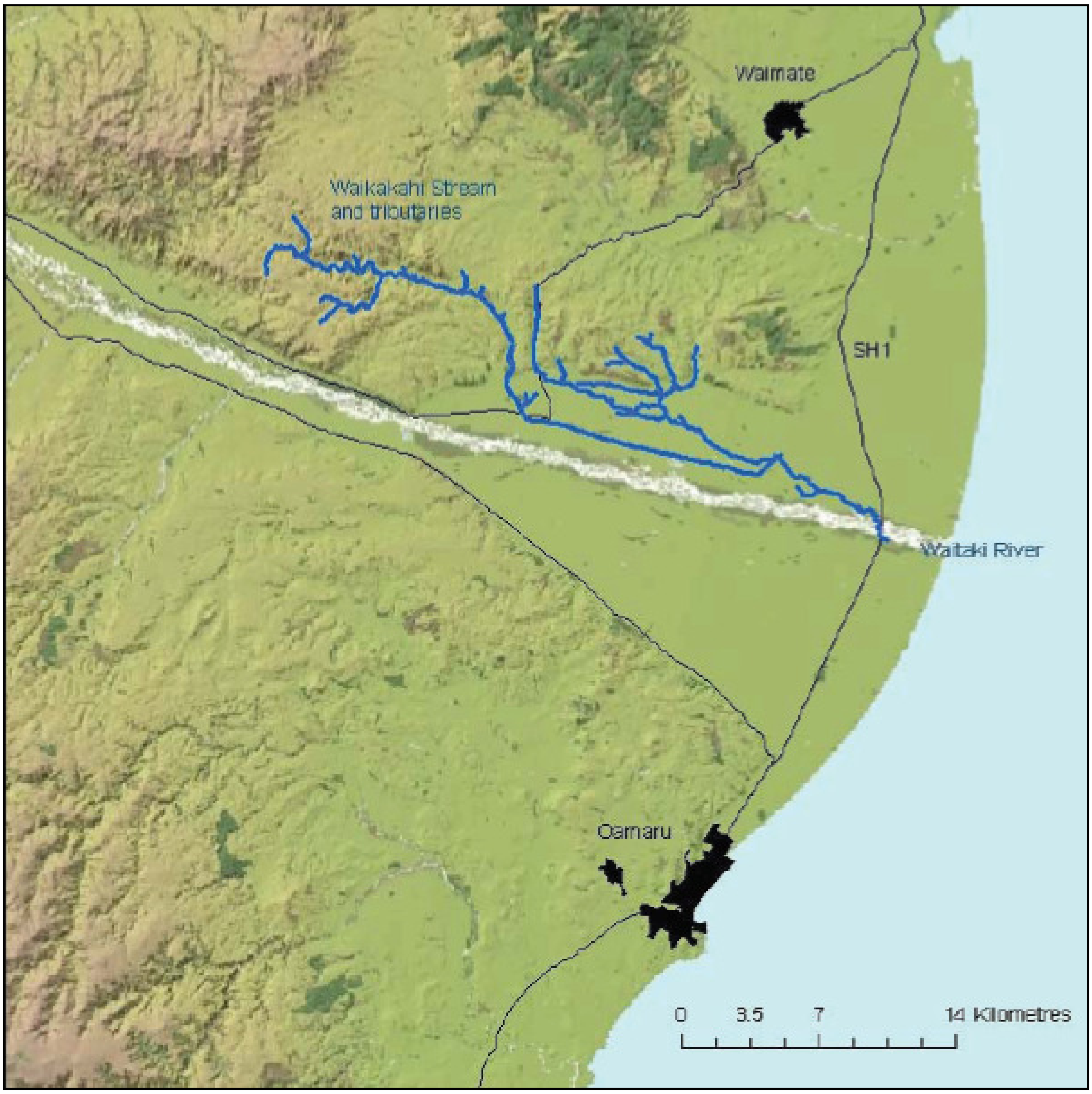

Figure 1.6: Location map of the Waikakahi Stream and tributaries which make up the Waikakahi catchment. From "Water quality in selected dairy farming catchments" by Ministry for the Environment, Publication number: ME 944, 2009, p. 60.

Irrigation is necessary in the catchment due to the combination of low rainfall, 600 mm/yr, and limited soil water-holding capacity (Monaghan et al., 2009a; Monaghan et al., 2008; Russell et al., 2006). Ninety five percent of the flat land in the catchment is irrigated by a mix of border-dyke and spray irrigation. Border dyke irrigation is a highly energy efficient form of irrigation as it relies on gravity to deliver water to paddocks. It can have low water-use efficiency depending on the construction and nature of the borders as well as the farm management strategies. Under border-dyke irrigation, any excessive wipe off water generated, which is the water that is not absorbed by paddocks, is drained or runs into surface water (Houlbrooke, 2007). This increases the flow in the Waikakahi Stream and changes the stream hydrology. Irrigation usually occurs during summer when water flow in lowland streams would naturally be at its lowest. It creates a reversal in the natural hydrological cycle of the Waikakahi Stream (Meredith et al., 2003). Summer flows are 4-9 times higher than the winter flows (Monaghan et al., 2009a).

The majority of irrigation water in the Waikakahi catchment is supplied through the Morven-Glenavy-Ikawai (MGI) Irrigation Scheme which began in the 1990's (Crossman, 2009). MGI were recently successful in updating their consent conditions to allow irrigation of an extra 8,200 ha (82 km²). This brings the total area to 27,000 ha (270 km²). This will be achieved by improving efficiency of irrigated farms as opposed to increasing the water take. Farm environment management plans (FEMP) are compulsory for all new water users as a condition of the updated consent (Aqualinc, 2008). As suggested by the name FEMP covers a range of aspects of the farm business that impact on environmental issues. They include a nutrient budget which outlines where nutrients enter and exit the farm system. FEMP will be independently audited. FEMP are compulsory for new irrigators under MGI's consent conditions, but MGI have gone beyond their consented requirements and will require FEMP for all irrigators as part of their irrigation supply agreements (Environment Canterbury, 2010b).

Main environmental concerns

Border dyke or flood irrigation, is the dominant irrigation method used in the Waikakahi Catchment (Crossman, 2009). Farm surveys taken in 2009 found approximately 70% of irrigation in the catchment is border dyke (Campbell et al., 2010; Monaghan et al., 2009b). The other irrigation is from lower application rate spray systems such as k-line pods or central pivot (Russell, 2003). Figure

1.7 illustrates how border dyke irrigation operates. As the wipe off water runs over land it captures and carries P, N and faecal bacteria from the soil, fertiliser and urine or dung patches. The contaminants are then carried into the Waikakahi Stream, contributing to poor water quality (Carey et al., 2004; Close et al., 2008; Monaghan et al., 2009a).

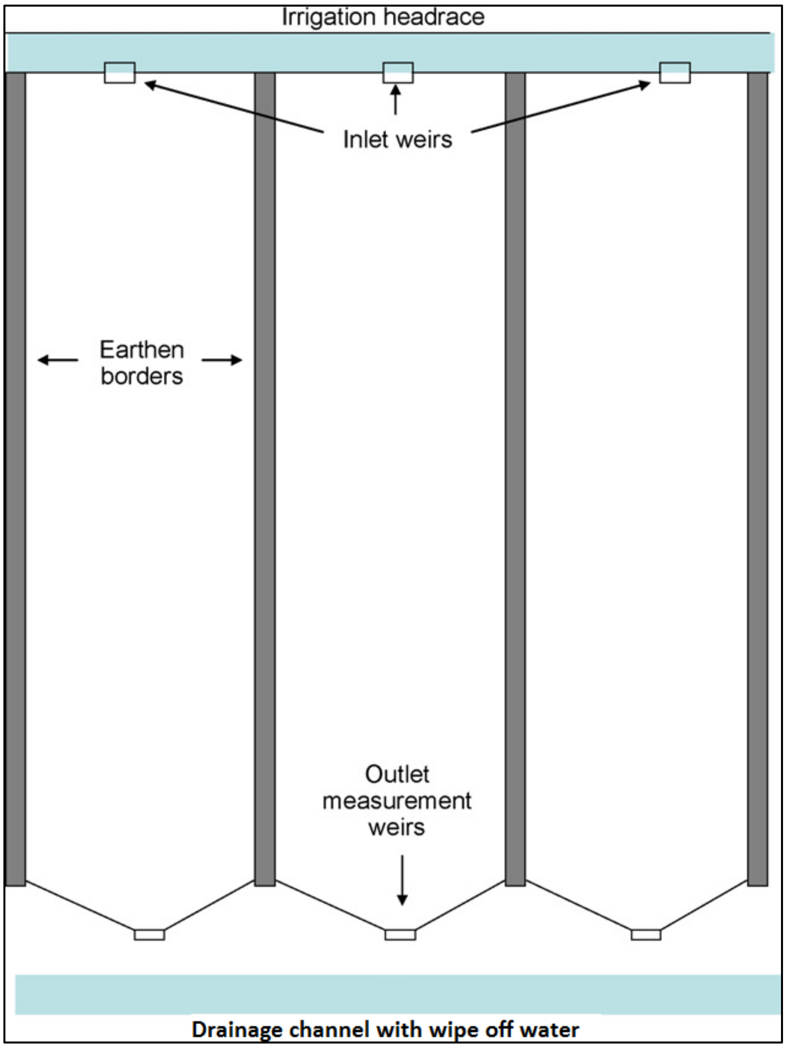

Figure 1.7. Diagram of a typical border dyke drainage system, depicted as a perspective view of a paddock. From "Linkages between land management activities and stream water quality in a border-dyke irrigated pastoral catchment", by Monaghan et al., Agriculture, Ecosystems and Environment, 2009a, p. 204.

On average 2.7 kgP/ha/yr are lost in the catchment (Campbell et al., 2010). These levels are perceptibly high because of the influence of the irrigation wipe off water (Wilcock et al., 2007). This P load is higher than the average for other monitored dairy catchments (except for the Inchbonnie catchment) which range between 0.3-1.2 kgP/ha/yr (Wilcock & Duncan, 2009). However, P is not the main nutrient of concern for the benchmarking project. Total P levels in the Waikakahi catchment have remained steady during the BPDC project. It is also likely that the increased water use efficiency required under the new MGI consents will go some way towards improving the P loss from wipe off water.

Nitrogen is the main nutrient of concern in the catchment. Total N losses have increased approximately 30% since BPDC monitoring began in 2001. On average 36 kgN/ha/yr are lost to the Waikakahi stream (Campbell et al., 2010). In comparison the average loss in the South Canterbury area is 20 kgN/ha/yr (Monaghan et al., 2009a). Waikakahi has the highest N loss out of the five monitored dairy catchments (Wilcock & Duncan, 2009). This is because the soil is free draining with limited water holding capacity so N tends to leach through (Monaghan et al., 2009a). Nitrates which make up a proportion of TN have potential to increase plant growth and toxicological effects on sensitive species such as trout (Hickey & Martin, 2009). A clear passage for drainage and a habitat for trout spawning were two of the key values of the Waikakahi catchment identified by meetings with dairy farmers and other catchment stakeholders (Monaghan et al., 2009b). Therefore the benchmarking project will focus on reducing TN losses in order to decrease the negative impact of nitrates.

1.5 Structure of thesis

This chapter has introduced the thesis. The purpose and aims of the study have been presented as well as a description of the contrasting catchments which provide the study areas for this research. Chapter 2 presents the conceptual context which forms the foundation of this research. The history of the dairy industry in New Zealand, New Zealand's position in the international dairy market and the environmental impact of dairying are described to provide a reference frame in which the nutrient benchmarks will sit. The first research question, what is a sustainable milk production system?, is also answered. The research gap is identified in Chapter 3 through the description of the current systems for nutrient management in New Zealand and reasons that the implementation of nutrient benchmarks is necessary.

A mixed method approach is employed in this research. As a consequence Chapter 4, the methodology chapter, is divided between the two methodologies employed. The qualitative telephone interviews are described followed by the quantitative water quality modelling. Chapter 5 is dedicated to the results. This chapter is also divided into two sections which present the results of the two methods separately.

The results of the two methods are discussed together in Chapter 6. The remaining research questions will be answered in order to determine whether the introduction of nutrient benchmarks to the two catchments will help achieve sustainable milk production systems. Chapter 7, the final chapter, is dedicated to summarising the main findings of this research and making recommendations related to the nationwide implementation of the benchmarks.

Chapter 2 HISTORY AND GROWTH IN THE NEW ZEALAND DAIRY INDUSTRY

2.1 Introduction

The dairy industry in New Zealand has undergone rapid growth in the last two decades. It has expanded into new regions and intensified in traditional dairy regions. The result of this growth is twofold. It boosted dairy production to become the country's largest export earner (Houlbrooke et al., 2004; Statistics New Zealand, 2009, 2010). It also increased the environmental footprint of dairying particularly in regard to nutrient losses to water ways. These nutrient losses are a major contributor to degraded ground and surface fresh water quality in New Zealand (Buchan et al., 2006; Chan, 2010; Houlbrooke et al., 2004). This chapter looks at the history and growth of the dairy industry in New Zealand and why the associated degradation of water by nutrients is an issue. It discusses the current approach to nutrient management by regional councils under the Resource Management Act (1991) and why this has not adequately managed non-point source discharges of nutrients.

2.2 The dairy industry in New Zealand

2.2.1 History and current structure

Dairy farming in New Zealand originated in 1814 when missionary Samuel Marsden imported a bull and two cows (Fonterra, 2011c; New Zealand Dairy Industry, 2011). The first New Zealand dairy farms provided milk, butter and cheese for local supply. The advent of refrigerated shipping created the potential for an export market. The first shipment of dairy products was exported from Dunedin to London in 1882 (New Zealand Dairy Industry, 2011). London and the United Kingdom became New Zealand's largest dairy export market. They remained so until the entry of UK into the EU in 1973.

New Zealand's dairy industry is structured in dairy cooperatives. These cooperatives began to form in the late 1800's and were created to pool and maximise resources and power. Historically they were regionally based and by the 1930's there were more than 400 dairy factories owned by cooperatives (Fonterra, 2011c). The New Zealand government created the Dairy Export Produce Control Board

(Dairy Board) in 1923 to provide control over the marketing of all dairy exports (Conforte et al., 2008; DCANZ, 2011).

New Zealand's export market changed in 1973 when Britain joined the European Union (EU). The EU places import tariffs and quotas on goods from outside the EU. These trade barriers meant the market for New Zealand dairy products in the UK was reduced. A quota for butter was negotiated but there was the need for adjustments in the New Zealand dairy market in order to remain viable (Conforte et al., 2008). This was achieved as the Dairy Board focused on diversifying markets and export products, particularly in South East Asia (Conforte et al., 2008; Fonterra, 2011c). In 1984 the Labour government of the time removed all farm subsidies in New Zealand. Most countries still have these subsidies which maintain minimum export prices and provide trade barriers to protect domestic product (Edwards & DeHaven, 2002). Sheep and beef farmers were heavily affected by the subsidy removal. The loss of subsidies resulted in considerable uncertainty of income. This, combined with an increase in interest rates and fertiliser and pesticide costs at the time, resulted in a decline in the profitability and land prices in the market (Barnett & Pauling, 2005). The dairy industry on the other hand had recently diversified its international markets and export products and had very few subsidies on its product. As profits from dairy continued to rise investment in the dairy industry increased (Barnett & Pauling, 2005).

The smaller regional dairy cooperatives continued to merge. They formed larger dairy cooperatives which benefited from the increased capital and could develop more sophisticated processing plants to deal with the increased milk production. In 2001 the two largest remaining cooperatives and the New Zealand Dairy Board merged to form Fonterra. Fonterra is the dominant player in the New Zealand dairy industry and represents 95% of New Zealand dairy farmers (Gray & Le Heron, 2010; Smith & Montgomery, 2004). The sole exporter status was revoked from the New Zealand Dairy Board after the merger (Gray & Le Heron, 2010). There are smaller milk companies such Tatua, Synlait and Westland Milk Products that process in some local areas. While these dairy companies operate and export niche products Fonterra is the main exporter and marketer of New Zealand dairy products.

Currently the United States, China and Japan are the major export markets as well as other smaller Asian countries (New Zealand Dairy Industry, 2011). Figure 2.1 shows how Fonterra trades in multiple international markets; New Zealand milk products are sold in 140 countries (Conforte et al., 2008). New Zealand produces approximately 15 billion litres of milk per year and exports more than 95% of this (Conforte et al., 2008; Gray & Le Heron, 2010). Concentrated milk products in the form of whole or skim milk powder are the main exported product. Other exports include milk and cream, buttermilk, whey, butter and their related products (Conforte et al., 2008).

When the New Zealand Dairy Board was disestablished in 2001 the export and marketing function was merged with Fonterra. It was decided that the other industry benefits that the Dairy Board provided, such as research, should be continued for all New Zealand dairy farmers (Conforte et al., 2008; DCANZ, 2011). Dairy InSight and Dexcel were created. The levy from dairy farmers was paid to Dairy InSight. Dairy InSight administered the levy to various research development and education providers to further the dairy industry. Dexcel was the lead provider of this research development and on farm education. In 2007 dairy farmers voted to merge the two and DairyNZ was formed (DairyNZ, 2009a).

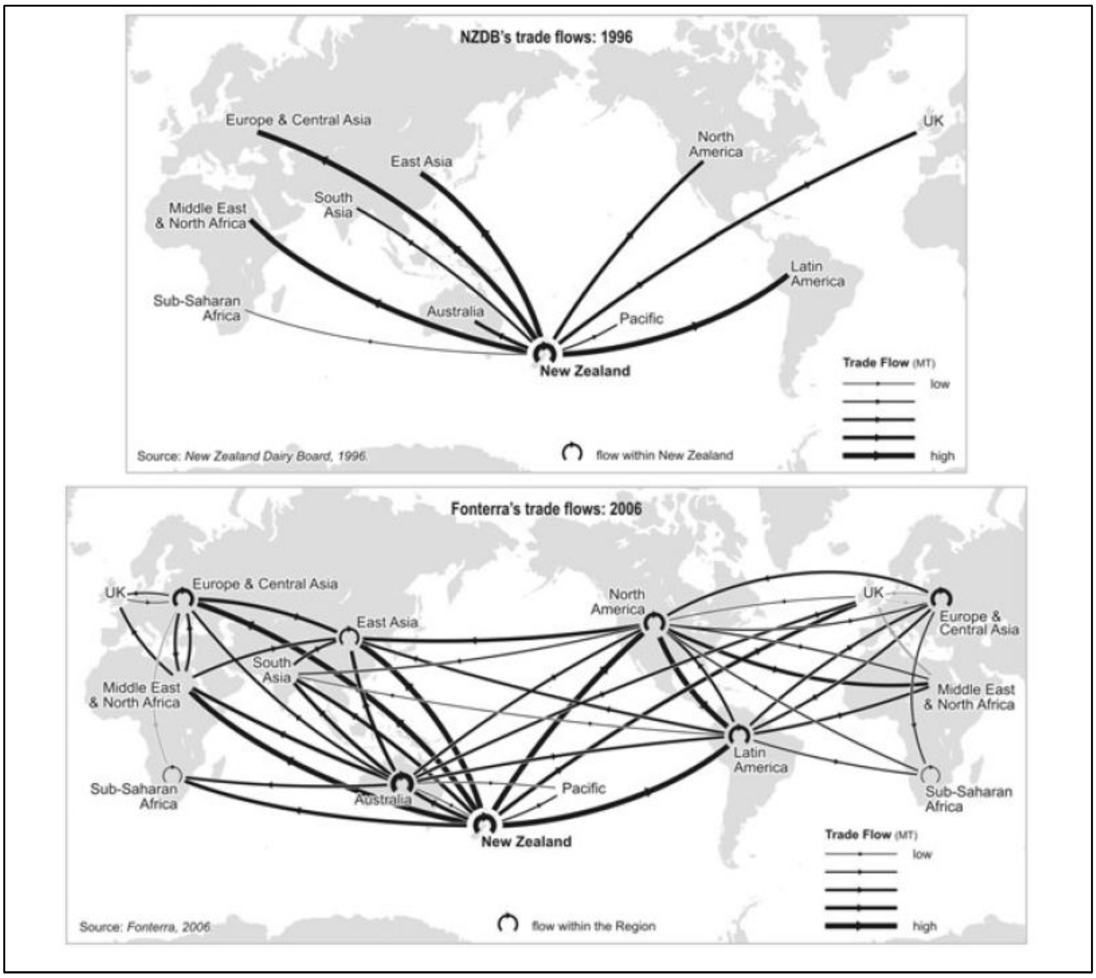

Figure 2.1. Diagram comparing New Zealand's dairy trade flows in 1996 under the New Zealand Dairy Board (NZDB) (on the top) and the international dairy trade flows including those established by Fonterra as at 2006, five years after the co-operative merger (on the bottom). It depicts how the flows have changed and the emergence of additional flows post NZDB. Adapted from "Globalising New Zealand: Fonterra Co-operative Group, and shaping the future", by S. Gray and R. Le Heron, 2010, New Zealand Geographer, 66, p.8.

DairyNZ is an industry good organisation whose role is to work in the best interest of New Zealand dairy farmers to enhance their profitability, sustainability and competitiveness. It is funded through a combination of a milk solids levy from all dairy farmers and government investment (DairyNZ, 2009a). Every four years the farmers vote on the continuation of this funding for DairyNZ. DairyNZ works with the Dairy Companies Association of New Zealand (DCANZ) and individual milk companies to help develop dairy industry strategies and deliver results that benefit dairy farmers in

New Zealand. DCANZ is an association of New Zealand dairy companies which formed to work collectively on public policy issues of importance to dairy companies within New Zealand and overseas (DCANZ, 2011).

The dairy farmers levy is currently invested in five different areas (DairyNZ, 2009a) :

- Adoption- Improving farmers' access and uptake of research and technology developments as well as information sharing with other farmers.
- Productivity- Developing tools and solutions to improve farm practice and increase productivity.
- On-farm innovation fund- Research fund for projects which show innovation in research or design.
- People and Business- Developing expertise and businesses for the future of the industry.
- Sustainability- Environmental, biosecurity and animal welfare issues as well as promotion of the dairy industry in New Zealand. Nutrient management and the benchmarking project fits into the sustainability area.

2.2.2 International dairy market

The international dairy market is volatile and sensitive to price fluctuations which has been illustrated in the last five years of trading (Hauser, 2010; Jongeneel et al., 2010; Westland Milk Products, 2010). This fluctuating price trend was also seen in other commodity based feed and resource markets over the same time period (Jongeneel et al., 2010). There are several factors that influence the price volatility of dairy products internationally. The dairy industry is linked into other markets in the global economy such as the energy market and the currency market. When these markets rise or fall there is a corresponding rise or fall in the cost of producing or trading dairy products (Jongeneel et al., 2010; Kilsby, 2010).

The small percentage of milk products traded relative to those produced globally creates a commodity market that is very sensitive to international changes in supply and demand. A small change in the supply or demand results in a large change in the free global trade of products. Hauser

(2010) suggests that a 1% movement in global supply and demand would result in a 14% shortage or surplus in the free global trade of dairy products from New Zealand and Australia combined. The dairy processing plants within these countries, including Fonterra, do not have the storage or funds to buffer the shortage or surplus. The result is a change in the price of milk products (Hauser, 2010). Supply is affected by environmental factors such as drought, economic factors such as the global recession or increases in production by smaller export suppliers. Demand in the dairy industry is usually more stable than supply. It has recently been affected by increased economic growth in developing countries that previously did not have the demand and by stockpiling for government aid (Hauser, 2010; Jongeneel et al., 2010; Westland Milk Products, 2010).

Government policy such as subsidies on dairy exports and tariffs or non-tariffs on trade by the European Union and United States further distort the supply and demand of global dairy products ("World Dairy Situation", 2010). Market intervention by the EU and US during the 2008/2009 financial crisis was useful to New Zealand dairy farmers. It meant excess milk products were bought and did not flood the market which would have dropped prices. Conversely government subsidies within EU and US domestic markets incentivise local producers to produce surplus milk. Their government will then subsidise this extra milk to place it into the world market. This means the export price of milk is kept higher than the supply dictates, which is damaging for the milk price received by New Zealand dairy farmers (Hauser, 2010; "World Dairy Situation", 2010).

The global dairy market is constantly evolving. The global demand for milk supply is growing at approximately 2% per year. Milk fits in as a well needed protein source in the diets of upcoming countries for example those in Asia, the Middle East and Latin America. Richer economies and modern western countries also require it as part of their diet. This diet also comes with associated concerns about health and nutrition (Gray & Le Heron, 2010; "World Dairy Situation", 2010). It is likely milk will remain a valuable import to provide for both of these demands as it is almost a complete food. China is becoming the fastest growing importer of milk products, but also has the fastest rate of growth in global production (Conforte et al., 2008; "World Dairy Situation", 2010). The EU is working on abolishing milk quotas and reducing market intervention on dairy products

(Jongeneel et al., 2010). There is much speculation over the impact this will have on the global dairy prices. It is thought that it will contribute to further volatility (Jongeneel et al., 2010; Westland Milk Products, 2010) but this may not be the case if it reduces the supply of excess milk at inflated prices as mentioned above.

Fonterra is at the forefront of the development of trade in the international dairy market. Figure 2.1 illustrates how Fonterra has expanded its export flows internationally. It actively shapes the global dairy scene through continuous development of this trade flow. Fonterra manages the gDT (global dairy trading) website which is a leading indicator of market dairy prices (Gray & Le Heron, 2010). Fonterra is able to maintain its competitive edge because worldwide only 6% of milk products that are produced are traded, the rest are sold domestically (Jongeneel et al., 2010). Fonterra does not and need not source all of its milk from New Zealand. A fifth of Fonterra's milk is sourced and produced in countries outside New Zealand and this amount looks set to increase. It has a major processing presence on four continents (DairyNZ, 2009a; Gray & Le Heron, 2010; New Zealand Dairy Industry, 2011). This helps Fonterra to meet growing international demand for milk products which cannot be met from New Zealand alone. New Zealand will continue to remain significant to Fonterra; it is where its stakeholders are located. There is also a lot of value in the New Zealand Milk Products brand because of the standard of milk product and New Zealand's environmental reputation. This will be discussed in Section 3.4.4: National and international reasons to introduce nutrient benchmarks.

2.3 Environmental concerns around dairying

The recent growth of the dairy industry has been accompanied by an increase in the environmental footprint of dairying in milk production areas. Expansion and intensification of dairy farmed areas has resulted in an increase in the volume of pollutants on land with the potential to enter water bodies. The impact that dairying has on water quality is a dominant environmental concern to both the dairy industry and the New Zealand public (Buchan et al., 2006; Chan, 2010; Houlbrooke et al., 2004). There are four main pollutants on dairy farms with the potential to enter water from land: suspended solids, faecal matter and the nutrients phosphorus and nitrogen. The sources of these pollutants, reasons why they are environmentally concerning and the transportation method from land to water are summarised in Table 2.1.

Nitrogen and phosphorus are pollutants of prominent concern. They are the focus for Dairy NZ's benchmarking project as they are major contributors to degraded ground and surface fresh water quality in New Zealand. Nitrogen (N) and phosphorus (P) are necessary on all farms because they are essential for the growth of plants and animals (Briggs & Smithson, 1985; Chan, 2010; Smith et al., 1999; Tchobanoglous & Schroeder, 1987). Nitrogen is required by all living cells for the synthesis of many of their biomolecules. Phosphorus is an important component in living cells and is present in nucleic acid (Briggs & Smithson, 1985; van Spanning et al., 2006).

One way that New Zealand dairy farms increase profitability is by using N and P for the purpose of optimising pasture and animal production (Monaghan et al., 2007a). Historically this has not been achieved through efficient use of N and P or concern for the environmental impacts. As a result dairy farms contain high concentrations of nutrients which are excess to those needed for production. As described in the following sections these excess nutrients are found in surplus or overloaded fertiliser and animal excretions (Wilcock et al., 1999). It appears that farmers are willing to accept these losses if farm profitability and productivity do not suffer (Bewsell & Kaine, 2005). This is illustrated in the results of a series of surveys on dairy farmers regarding decisions around farm dairy effluent management, which is a source of both P and N. It was found that management was driven by on farm convenience as opposed to environmental concern (Bewsell & Kaine, 2005).

The input of too much N and P to a water body has serious impacts on water quality. Understanding the sources, transportation and transformation processes involved is essential to the management of nutrients and their associated water quality degradation. These sources and problems were shown briefly in Table 2.1 and will be explained in detail for N and P in the following sections.

Table 2.1. Main pollutants sourced from dairy farms that affect water quality. Adapted from "Managing Farm Runoff" by Environment Waikato, 2011b, http://www.waikatoregion.govt.nz/ Environment/ Natural-resources/Land-and-soil/Managing-Land-and-Soil/Managing-farm-runoff/.

Pollutant	**Why is it a problem?**	**Source**	**Transportation from land to water**
Faecal matter (bacteria and viruses, in particular *E. coli*)	• Human health risk from swimming and drinking • Can affect stock health if present in stock water	Dung from stock Farm Dairy Effluent irrigation	• Overland run-off to surface water bodies • Direct deposition through stock in water bodies, point source discharge of effluent
Suspended sediment	• Degrades water quality and clarity • Makes water unsafe for swimming	Slips and hillside erosion Stream bank slips, erosion and trampling Surfaces of tracks, races and paddocks	• Overland run-off to surface water • Direct deposition through bank collapse or erosion or disturbance
Total Nitrogen (TN) a common measurement of nitrogen in waterways and includes all forms of nitrogen, both inorganic (nitrites, nitrates and ammonium) and organic nitrogen Of main concern is Nitrite-Nitrate Nitrogen (NNN)	• Essential for nuisance plant and algae growth in waterways • Algae and nuisance plants degrade water quality parameters, block water intakes and make water unpleasant for recreation and drinking • Ammonia can be toxic to fish	Urine and dung from stock Nitrogen in fertilizer Farm Dairy Effluent	• Overland run-off to surface water • Leaching to groundwater • Direct deposition through stock in water bodies or point source discharge
Total Phosphorus (TP) a common measurement of phosphorus in waterways and includes all forms of phosphorus including Inorganic P in original materials such as rocks or compounds coating mineral particulates, Organic P in plants and soil fauna or debris and Soluble P in soil solution Of main concern is Dissolved Reactive Phosphorus (DRP)	• Essential for nuisance plant and algae growth in waterways • Algae and nuisance plants degrade water quality parameters, block water intakes and make water unpleasant for recreational and drinking	Dung from stock Phosphate in fertiliser Farm Dairy Effluent Soil sediment	• Overland run-off to surface water • Direct deposition from erosion sources, stock in water bodies, point source discharge and drains

2.3.1 Nitrogen

Nitrogen (N) is present in all living cells and is the fourth most common element in living tissue. In a natural system the majority of nitrogen is reserved in the atmosphere as N_2 gas which is biologically unavailable. N_2 is fixed by micro-organisms and occasionally lightning into useable inorganic nitrogen. In this form N can be taken up by plants and turned into organic N. Plants are in turn consumed by animals transporting N up the food chain. N is released back into inorganic components through excretion or decomposition of animals or plants, completing the cycle (this is illustrated in Figure 2.2) (Briggs & Smithson, 1985; Thomas & Tracey, 2005; van Spanning et al., 2006). The amount of N in bioavailable forms (available for uptake by plants and microorganisms) has increased through human intervention. Nitrogen input into the terrestrial cycle has almost doubled through anthropogenic inputs. Worldwide, humans now contribute as much fixed N to ecosystems as all the natural sources together (Smith et al., 1999).

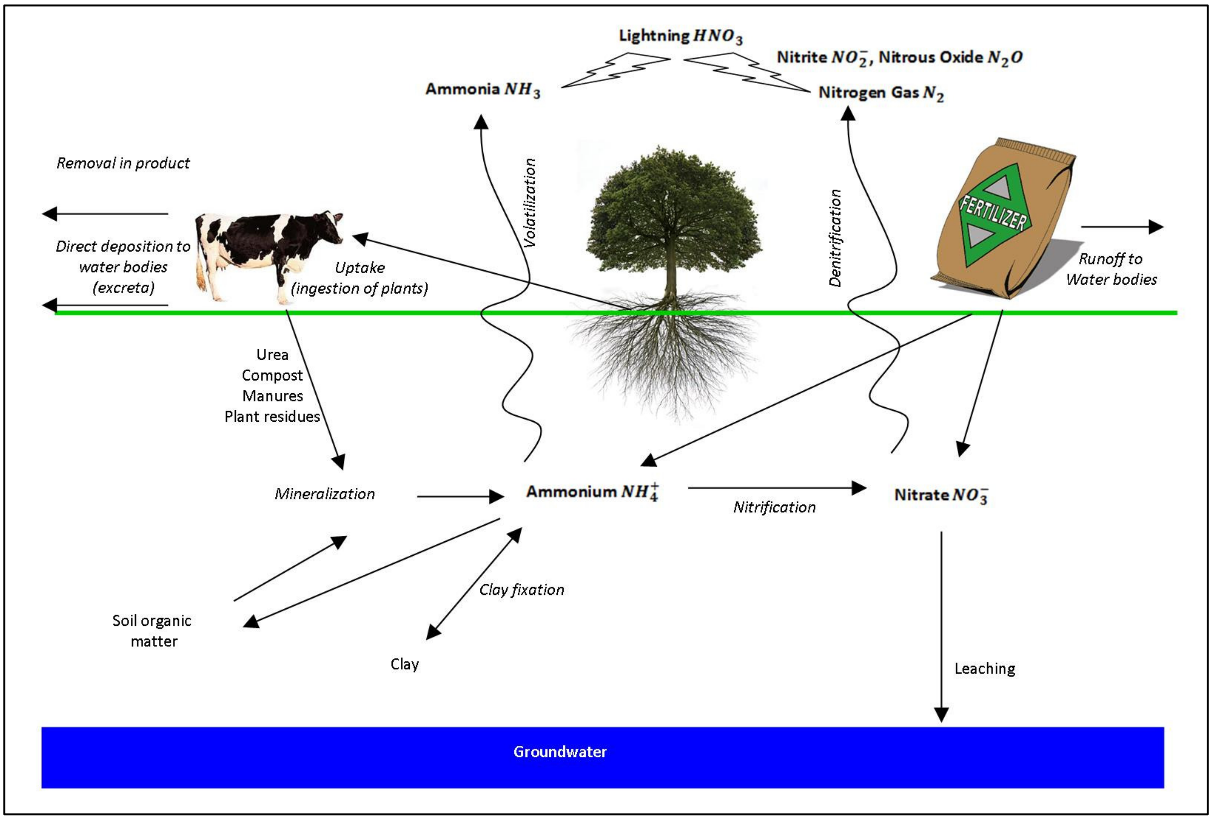

Figure 2.2. Simplified nitrogen cycle on a dairy farm. Adapted from “The nitrogen and phosphorus cycles in soils” by Espinoza et al., 2005, http://www.uaex.edu/Other_Areas/publications/PDF/FSA-2148.pdf

Ammonia in fertiliser and cultivation of nitrogen fixing crops such as clover are two main sources of bioavailable N on dairy farms above the naturally occurring volumes (Thomas & Tracey, 2005). It is also imported into a dairy farm system through feed supplements. Nitrogen leached from fertiliser use is generally low under average management conditions so is not the most important source of N loss on New Zealand dairy farms (Monaghan et al., 2007a). The most important source is urine from cows. This occurs because N is inefficiently converted by dairy cows from feed into product (milk and meat). The protein dietary requirements of the stock are much less than the protein content of the pastures so the excess N consumed as protein but unused within the animal is returned to the pasture as urine. This urine is either collected as farm dairy effluent or deposited by stock onto paddocks in patches which have a much higher N concentration than the surrounding pastures (Monaghan et al., 2007b). Nitrogen in urine is in the form of ammonia; which is an unwanted by-product of animals and is readily bioavailable. Through the process of nitrification ammonia is converted into nitrate which is highly soluble in water (Briggs & Smithson, 1985; Thomas & Tracey, 2005; van Spanning et al., 2006). Both ammonia and nitrate are lost off dairy farms to water via leaching and run-off which is illustrated in Figure 2.2.

Research into mitigation measures which reduce N loss from New Zealand pastures have found there are products and practices which achieve better management of N. Examples include using N process inhibitors which improve N efficiency in pastures. This is achieved by slowing conversions of N and keeping it as ammonium which is more readily bound to soils therefore not leached to water. As well as farm system changes such as reducing the time stock spend on pasture in times of high drainage and sourcing low-N feed supplements (Monaghan et al., 2007a).

2.3.2 Phosphorus

Phosphorus (P) is required within plants and animals for energy transfer as well as passage of genetic information. Phosphorus is found in the bones and teeth of vertebrates as calcium phosphate (Thomas & Tracey, 2005). Unlike nitrogen, P is absent in the atmosphere. It is highly reactive so is not found by itself in nature. Instead it is usually present as a phosphate such as orthophosphate.

Phosphorus in the environment is found in three main forms (Thomas & Tracey, 2005):

- Inorganic P in original materials such as rocks or compounds coating mineral particulates
- Organic P in plants and soil fauna or debris
- Soluble P in soil solution

The inorganic P which is tied up in rocks is generally biologically unavailable. Erosion and weathering do release bioavailable P from rocks but the majority is highly insoluble and carried to permanent sinks in the ocean. Chemical weathering also releases some soluble phosphate. Orthophosphate, a soluble form of phosphorus, is the only form of bioavailable P for plants and microorganisms (Thomas & Tracey, 2005). As shown in Figure 2.3 soluble P can be taken up by plants which are in turn taken up by animals and converted into organic P. Mineralisation converts organic P back into a soluble form for the uptake by plants which completes the cycle.

Human activity has increased the amount of bioavailable P. Phosphorus that was previously unavailable is mined and processed for phosphate fertilisers which are added to soils to maintain or increase fertility (Smith et al., 1999). Fertiliser P binds to soil and organic particles and in doing so becomes resistant to leaching. Plants are then able to use this bioavailable P. Phosphorus is lost when soils lack binding metals, clay, silt or organic material to bind to. Phosphorus then leaches down into groundwater. Erosion, weathering or run-off of soil bound with P particles into waterways also results in P loss (Thomas & Tracey, 2005).

Unlike N, P loss from fertiliser, or farm dairy effluent applied as fertiliser, may be the most important source of P loss from New Zealand dairy farms. It is dependent on several factors including the form and timing of the application. Application during times of high rainfall and overland flow or applications of dissolved P forms will intensify the risk of loss. Mitigation of P loss from these source focuses on reducing the solubility of the fertiliser to slower release forms as well as ensuring pastures are maintained to recommended Olsen P values. Olsen P values come from soil tests and provide an indication of the biological and optimum value of P in soils. Keeping Olsen P values above optimum will unnecessarily increase the volume of P with the potential to run-off pasture (Smith et al., 1999).

Reducing losses from dung requires excluding stock from waterways in addition to reducing the amount of time stock spend on pastures in periods of high overland flow.

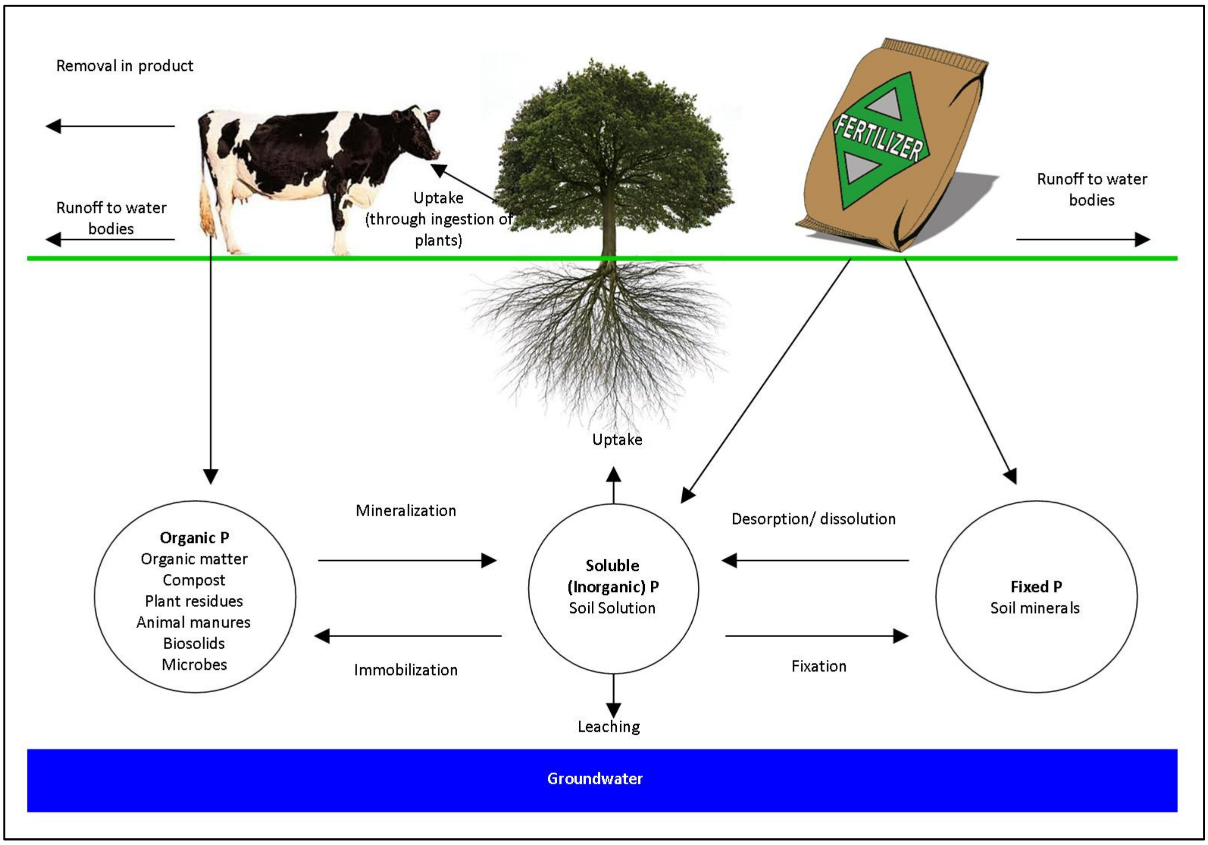

Figure 2.3: Simplified phosphorus cycle in soils on a dairy farm. Adapted from "The nitrogen and phosphorus cycles in soils" by Espinoza et al., 2005, http://www.uaex.edu/Other_Areas/publications/PDF/FSA-2148.pdf

2.3.3 Why are nitrogen and phosphorus an issue in New Zealand waterways?

Nitrogen and phosphorus are an issue in New Zealand waterways because of the environmental impacts they generate. Furthermore there are cultural, social and economic impacts of N and P in waterways. These are often as a result of the environmental impacts and must also be taken into consideration when discussing the implications of N and P in New Zealand waterways.

Environmentally

There are both direct and indirect negative environmental effects resulting from increased nitrogen and phosphorus inputs to waterways. The direct effects involve increases in Total Nitrogen (TN) and

Total Phosphorus (TP) levels in the waterbodies which may cause excessive plant and algal growth (McDowell et al., 2009; Smith et al., 1993). Plant growth includes periphyton, small benthic algae who attach themselves to the bottom of submerged surfaces in water. As well as macrophytes which are larger aquatic plants (McDowell et al., 2009; Smith et al., 1993). The plant growth stimulates indirect changes in the biotic communities and further changes in the water quality and clarity (Harper, 1992; Schindler & Vallentyne, 2008; Smith et al., 1999; Wilcock et al., 2007). The process by which over-fertilisation of water bodies by N and P occurs and the resulting biological effect is eutrophication (Harper, 1992; Schindler & Vallentyne, 2008; Smith et al., 1999).

The yield of plants in water bodies is controlled by the supply of nutrients to that water body (Schindler & Vallentyne, 2008; Smith et al., 1999) and is affected by three main factors. Firstly, the abundance of nutrients in relation to the ratio required for growth. This ratio can differ in individual streams but in general is 16:1 N:P. If the ratio is considerably different from this, growth is limited by the factor that is lacking. Introduction of the limiting nutrient will greatly increase the growth of plants. The concentration of the nutrients is the second factor. High concentrations of both nutrients may cause growth despite one nutrient being limiting. Chemical form is the final factor; the nutrients must be in a form that is readily available (McDowell et al., 2009). When nitrogen and phosphorus enter waterways at low levels they can have a favourable influence on plant yield and subsequent secondary production within the system (Hopkins, 1976; Stevenson et al., 2010). However, as the nutrient supply increases the aforementioned factors may become conducive to excessive and often nuisance plant growth.

The excessive plant and algal growth has a number of negative effects on the water body. Over the period of a day plants go through a cycle of photosynthesis and respiration. This causes significant diurnal variation in the dissolved oxygen and pH levels in the water column. Stream bed surfaces get smothered in plant or organic matter as well as sediment which becomes trapped as plants disrupt the water flow. This reduces habitat quality for macroinvertebrates and fish spawning areas (Smith et al., 1999; Stevenson et al., 2010). Both the diurnal variation and habitat disruption increase the probability of fish kills (Smith et al., 1999). Pollution sensitive species are lost diminishing biodiversity of the waterway (Wilcock et al., 2007).

Excess plant growth results in a build up of organic matter, both decomposing and filamentous periphyton mats on the floor of the water body. As this is broken down it further depletes the dissolved oxygen in the water altering water quality (Schindler & Vallentyne, 2008; Thomas & Tracey, 2005). Nutrient which has built up in the sediment can be released in soluble bioavailable forms as a result of the deoxygenation process which further drives the eutrophication. The build up of nutrients in plants and animals can be recycled in waterbodies for years after the nutrient supply has stopped (Harper, 1992; Thomas & Tracey, 2005).

Lakes “turn over” or mix from top to bottom during the year, usually in mid-winter. For the remainder of the year the lake is thermally stratified, warmer at the surface and cooler at depth. This seasonal mixing has important implications for water quality (Horrox, 2008). When the lake is thermally stratified the deeper water (called the hypolimnion) is isolated from the oxygen at the lake surface. Increase in plants in the lake bottom or decomposition of organic matter which has settled relies on the oxygen that was mixed in when the lake “turned over” mid-winter (Horrox, 2008). If the oxygen demand in the hypolimnion exceeds the oxygen supplied during turnover the bottom may become anoxic and sensitive aquatic life such as trout would die (Horrox, 2008). The depletion of oxygen in the hypolimnion is an important cycle to avoid. Once it begins in the lake positive feedback mechanisms tend to exacerbate them, further effecting water quality (Horrox, 2008).

If eutrophication is allowed to continue long term it will eventually lead to a complete loss in biodiversity and the water body infilling (Parliamentary Commissioner for the Environment, 2004, 2006). NIWA monitors the water quality of 134 lakes throughout New Zealand. Approximately half of them are in an eutrophic or worse state (Verburg et al., 2010). Lake Rotoiti in the Rotorua lakes district is an example of a eutrophic lake typical of those found in warmer catchments and areas with high pasture cover. A study in 1984 noted that eutrophication may be a natural feature of the lake as it is not in a particularly developed area and the rate of decline was slow (Vincent et al., 1984). Since then the eutrophication has worsened. It is likely this is due to an increase in land use development and a time lag in groundwater nutrients reaching surface water. A result of the eutrophication is the hypolimnion becomes devoid of oxygen for months of the year. Algal blooms have also affected this popular trout fishery. Figure 2.4 illustrates excess algal plant growth found in Lake Rotoiti.

Figure 2.4. Algal bloom found in Lake Rotoiti in the Rotorua Lakes District on the right, note the green colour in the water from the algal bloom on the left. From "Algae treatment for Lake Rotoiti" by Environment Bay of Plenty, 2011, http://www.boprc.govt.nz/news-centre/media-releases/february-2011/algae-treatment-for-lake-rotoiti/.

Culturally

Maori and Pakeha (non-Maori New Zealanders) have different views on the importance of water. Pakeha often tend to value water as a resource to be used. Uses of water may include; economically for irrigation or power, recreationally for swimming or fishing or utilisation for drinking water purposes. It can also be used as a carriageway for waste: human sewage is disposed of into rivers, lakes and the ocean throughout New Zealand. Maori in contrast have a special connection with the natural world, believing an interconnection exists between it and human kind (Royal, 2003). Through the creation story, man is a part of Papatuanuku (mother earth) and regulates her life support systems. We have a duty to protect Papatuanuku that comes from our whakapapa (family) connections (Royal, 2003). Failure to fulfil this obligation as kaitiaki (guardians) can be harmful to the physical and spiritual wellbeing of tangata whenua (people of the land) (Environment Waikato, 2000). Water is a particularly important feature of the natural environment. It is a taonga or treasure given to us by ancestors (Gibb & Bennett, 2007; Te Runanga o Ngai Tahu, 1999) without it no living thing can survive. When Papatuanuku and Ranginui were separated Ranginui wept tears for Papatuanuku which is the origin of water. Waterways are the veins that nurture Papatuanuku and their health is a reflection of the health of Papatuanuku (Williams, 2006).

Maori believe all living things to have Mauri. Mauri is a life essence or spark present in every entity given to it by Atua (God). Water is considered to be a living thing with a mauri of its own. This mauri varies between waterways depending on their spiritual and physical condition (Williams, 2006). Preservation of mauri is a key environmental concept for Maori. Human activities affect mauri and mauri is unable to protect itself. Activities such a mixing waters of different mauri, discharges of contaminants to water and changes to hydrological regimes degrade mauri. If this occurs the water resource as well as those who use or depend on it are at risk.

As a consequence of the Treaty of Waitangi Acts and the inclusion of some form of Treaty clause in most legislation post 1984 the unique relationship Maori have with the environment is given special status under the RMA (1991). The most significant of these are set out in Part II of the Act; Matters of National Significance. The relationship of Maori and their culture and traditions with their ancestral lands, water, sites, waahi tapu, and other taonga is a matter of national importance (section 6e). When managing the use, development, and protection of natural and physical resources all persons shall have particular regard to kaitiakitanga (section 7a) and take into account the principles of the Treaty of Waitangi (Te Tiriti o Waitangi) (section 8). Eutrophication is regarded as a type of pollution which desecrates or defiles mauri. Therefore the introduction of excess nitrogen and phosphorus to waterways is important culturally as it erodes Maori relationship with water. It prevents the taonga being available to the future generations (Te Runanga o Ngai Tahu, 1999; Williams, 2006). As a result it is in defiance of several sections of the RMA, 1991.

Socially and economically

The social issues caused by the introduction of excess nitrogen and phosphorus into water ways are both direct and indirect. There is a direct risk cause by excess nitrogen in waterways. It can pose a serious health risk if large amounts of nitrates enter drinking water. Ingestion of these nitrates can cause methaemoglobinaemia which is a condition that reduces the amount of oxygen released from blood into tissue. This is of particular concern for babies under six months however it is fairly uncommon in New Zealand (Ministry of Health, 2005). A 'Maximum Acceptable Level' of nitrate-nitrogen allowed in drinking water, equal to 11.3 mg/L, is set by the Ministry of Health (Ministry of Health, 2005; Monaghan et al., 2007a). Nitrate plumes can travel long distances in groundwater or become stored in soil to constantly replenish the nitrate supply. Once nitrates became present in groundwater they are very difficult to remove (Ministry of Health, 2005; Smith et al., 1999).

Indirect social impacts result from excess plant yield. Offensive tastes and odours are produced as the plant and organic matter break down. A general reduction in water based recreational activities may voluntarily or legislatively occur. The plants foul and catch fishing lines and nets and the resulting water quality may kill the game fish (Smith et al., 1999; Stevenson et al., 2010). Reduced water clarity dampens the aesthetic value we put on crystal clear lakes, such as Lake Taupo (Monaghan et al., 2007a; Schindler & Vallentyne, 2008).

Toxin-forming algal blooms are becoming more common in New Zealand lakes and river mouths, particularly during the warmer summer months. Blue-green algae has been present in the Rotorua lakes, particularly Lake Rotoiti (Hamilton, 2003). During the summer of 2009 a build up of the toxic algae Phormidium in the lower reaches of the Ashley River killed a dog and prompted Environment Canterbury to warn people to be careful when swimming or walking pets (Environment Canterbury, 2009a). Lake Ellesmere (Te Waihora) was also unsuitable for recreational use and drinking in the summer of 2009 due to Nodularia, a blue-green algal bloom (Environment Canterbury, 2009b). In the Waikato region health warnings are in place for several lakes within the region due to concerning blue-green algae concentrations over the summer of 2011/12 (Environment Waikato, 2011a).

The loss of the recreational, tourism and drinking water amenities through excess plant growth and algal blooms has a negative economic outcome (Smith et al., 1999). The presence of toxin-forming algal blooms in recreation waters prevent swimming, boating or fishing at peak recreation times. A Ministry for the Environment study into tourists' perception of New Zealand's environment found that if the clean green image was seen to be degraded, New Zealand could lose between NZ$530-938 million revenue from tourism (Thornton et al., 2001). The nutrients can also disrupt the flocculation and chlorination at wastewater treatment plants resulting in the need for further treatment. Additional plants in waterways can cause flooding in drainage channels as well as block intake screens for water takes. Both of these incur additional cost for the users (Smith et al., 1999).

Inefficient use of nutrients which results in them leaving the farm system and entering waterways means that they are no longer available for utilisation on the farm. This comes at an economic cost for farmers both due to losing nutrients that they have paid for as well as losing the additional product these nutrients would have contributed to (Ledgard et al., 1998; Monaghan et al., 2007a). Describing the loss of nutrients from farms as an economic cost, instead of an environmental cost to water quality, is a method which is employed by regional councils and agencies such as DairyNZ to help improve farmers understanding of nutrient management and change their management styles (Chan, 2010; Environment Canterbury, 2010a; O'Connor et al., 1996; Waikato Farm Environment Award Trust, 2002). Although managing and utilising nutrients for farm profitability is not always sufficient to reduce their environmental impact (Bewsell & Kaine, 2005; Monaghan et al., 2007a).

2.4 Current nutrient management framework under the Resource Management Act (1991)

2.4.1 The Resource Management Act (1991)

There is a need for better nutrient management practices on dairy farms to reduce the environmental, cultural, social and economic impacts discussed that are associated with excess nitrogen and phosphorus in New Zealand waterways. Regulation through the Resource Management Act (RMA) (1991) is the dominant way of dealing with these environmental issues in New Zealand. The RMA replaced 78 individual statutes and regulations to provide a singular overarching environmental legislation for New Zealand. Its purpose, under section 5(1), is to promote the sustainable management of natural and physical resources (Resource Management Act, 1991). The RMA is effects based legislation as opposed to prescriptive or activity based. The intent was to enable activities to proceed and only arbitrate if the environmental impacts were unacceptable (Environmental Defense Society, unknown; Ledgard et al., 1998). Section 5(2) of the RMA highlights this when it describes sustainable management as “managing the use, development, and protection of natural resources in a way, or at a rate, which enables people and communities to provide for their social, economic and cultural wellbeing and for their health and safety while-

a) sustaining the potential of natural and physical resources (excluding minerals) to meet the reasonably foreseeable needs of future generations; and
b) safeguarding the life-supporting capacity of air, water, soil, and ecosystems; and
c) avoiding, remedying, or mitigating any adverse effects of activities on the environment.”

The RMA established a tiered plan framework which delegates roles and responsibilities of natural resources management. Figure 2.5 illustrates how the responsibility is split from central government through to local government. The RMA should manage the environmental impacts of nutrients from dairy farms in New Zealand through both central and local government. This section will describe how central government has, up until very recently, provided little guidance around this. It also describes how nutrients are managed by regional councils (local government).

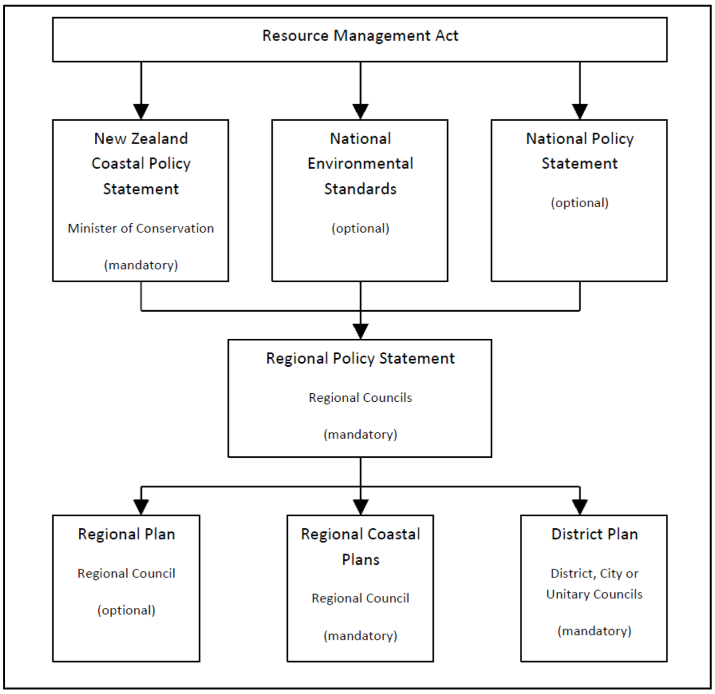

Figure 2.5. Resource Management Act (1991) Plan Framework

2.4.2 Central government management under the RMA

The RMA provides Central Government with the option to prepare National Policy Statements (NPS), and National Environmental Standards (NES). NPS are for resource management matters of national significance. They outline the objectives and policies to guide successive resource management decision making from national, regional and district levels. NES further this by providing consistent standards to be taken up at regional and district levels. The poor utilisation of NPS and NES is often discussed in freshwater management literature (Cullen et al., 2006; Memon, 1997). It has resulted in limited central government guidance to regional councils on freshwater management decision making, including management of nutrients discharging into waterways (Parliamentary Commissioner for the Environment, 2004).

A National Policy Statement for Freshwater Management was released in 2011, two decades after the RMA was first introduced. Environment Minister Nick Smith indicated that the long time frame occurred because it is politically difficult to produce an operative NPS in New Zealand (McCrone, 2011). The key purpose of the NPS is to set enforceable water quantity and quality limits. It requires regional councils to establish water quality limits for all bodies of freshwater in their region. If the water does not meet the limits they must implement methods to assist the improvement within a limited timeframe. In order to meet water quality limits regional councils will have to address methods to reduce non point source pollution (Ministry for the Environment, 2011b). There are still no legally binding National Environmental Standards for fresh water. The onus is back on regional councils to design and implement their own water quality standards. Environment Minister Nick Smith defends the decision not to implement water quality standards, stating decisions must be made at the lowest level to determine what is appropriate for each region (McCrone, 2011).

The most recent OECD report (2007) stated that a lack of legally binding NPS or NES made it arduous for regional councils to implement regulatory or economic measures to manage non point source pollution. It is therefore likely that the newly released NPS for Freshwater Management (2011) will provide some assistance to regional councils regarding nutrient management. Particularly as the operative NPS requires that specific conditions must be placed on discharge consents to ensure water quality targets can be met. At the time of this research it is too early to determine how beneficial the NPS will be for regional council management of non-point source discharges.

2.4.3 Regional council management under the RMA

Regional councils are the legislated environmental management agencies for natural resources in New Zealand. Their functions under Schedule 30 of the RMA, in particular 1(c) control the use of land and 1(f) control of discharges of containments into or onto land, air, or water and discharges of water into water, mean they are also responsible for regulating nutrient management on dairy farms. In particular this involves managing the discharge of nutrients from a farm system that have an impact on water quality. There are two manners in which nutrients are discharged from land to water; point source which occurs from a particular location, and non-point source which occurs from a diffuse location. Managing these sources to prevent excess nutrients entering waterways is an essential part of nutrient management. Point source discharges have been effectively controlled through the framework set up by the RMA. Regional councils have historically struggled to control non-point source discharge with the available regulatory management. The difference between point source and non-point source discharges as well as their management will be discussed in this section.

Point source discharges

Point source discharges occur at an identifiable place, for example through a pipe or drain. Rules and regulations established in the first round of regional plans focused on controlling point source discharges of contaminants into waterways, particularly farm dairy effluent (FDE). FDE consists primarily of the wash down water and animal wastes from milking sheds. It may also contain storm water, spilled milk, soil residue, feed residue, detergents and other chemicals used to wash down the shed (Cameron & Trenouth, 1999; Houlbrooke et al., 2004).

Prior to the 1950's the environmental effects of FDE were insignificant because of the low number of farms and low stocking rates. The waste that was produced during milking was mainly solid so could be scraped and distributed around the farm (Cameron & Trenouth, 1999). The popularity of high-pressure wash down hoses and herringbone sheds in the 1960's resulted in an increase in FDE generated for disposal. It was discharged without treatment into soakage ponds or into farm ditches which ran into streams. Public concern about the impact on aesthetics of waterways and water quality due to the discharge of contaminants also began to occur at this time. Farmers were encouraged to install ponds for treatment or discharge to land to avoid stricter regulation (Cameron & Trenouth, 1999). Two-pond systems were introduced in the 1980's to treat the FDE before discharge. They consisted of an anaerobic treatment pond and another larger pond which has layers of anaerobic and aerobic treatment. The effluent is then discharged to water. This system effectively removes sediment and Biological Oxygen Demand. However high concentrations of N and P remain in the treated FDE which is subsequently discharged into a waterbody (Houlbrooke et al., 2004; Monaghan et al., 2007a). The discharge from two-pond effluent systems has an adverse environmental impact on surface water quality. They are now discretionary activities in most regional plans so require resource consent.

Irrigation to land from sumps or ponds became the preferred method of FDE disposal from 1995 onwards to avoid directly discharging into waterways. Some regional councils also introduced maximum load limits for nitrogen in irrigated FDE. Irrigation to land is not a completely satisfactory solution to dealing with FDE; however it utilised the science and technology that was available in the

1990's. Issues include lack of awareness of factors such as the nutrient concentration of FDE or the soil infiltration capacity as well as management issues such a compulsory discharge at inappropriate times due to inadequate pond storage. These can lead to nutrients running off into surface waterways or lost through root zones to groundwater (Houlbrooke et al., 2004; Monaghan et al., 2007a).

Non point source discharges

Non-point source pollution differs from point source pollution because it enters water bodies from a diffuse source that is difficult to define. The exact location of the pollution may be unknown or spread over a large area. Section 2.3.1 Phosphorus and Section 2.3.2 Nitrogen describe how ineffective nutrient use results in excess N and P in dairy farm systems which are lost to waterways via leaching into groundwater or run-off into surface water. This is all non-point source nutrient loss. The scale of dairy intensification and expansion has resulted in non-point source pollution putting large pressure on surface water quality in New Zealand (Cullen et al., 2006; OECD, 2007).

The problem of non-point source nutrients has been apparent for at least the last decade (Cameron & Trenouth, 1999; Monaghan et al., 2007a; Office of the Minister for the Environment, 2009). A recent OECD report concluded that the management of non-point source pollution is a major issue for nutrient management in New Zealand (OECD, 2007). Despite this regional councils have struggled with controlling non-point sources of N and P. It has been argued in literature that this is because it is difficult to manage cumulative or diffuse impacts on the environment through the RMA (Environmental Defense Society, unknown; Ledgard et al., 1998). Partially because regulation of inputs or outputs of a particular nutrient into a dairy farm system is the opposite of the RMA's effects based legislation (Ledgard et al., 1998). It would prescribe how to do the activity of dairying as opposed to minimising an unacceptable effect. It is also partially because the RMA does not provide the tools to include management of non-point sources.

Milne (2008) and Salmon (2007) present an opposing argument. They maintain that the purpose of the RMA, as stated in Section 5, is to enable people and communities to provide for their social, economic and cultural wellbeing and health and safety while sustaining resources to meet future generations needs; safeguard the life-supporting capacity of air, water, soil and ecosystems and; avoid, remedy or mitigate adverse effects on the environment. Under Section 30 Functions of regional councils part 1.c.ii. "Every regional council shall have the following function(s) for the purpose of giving effect to this Act in its region: the control of the use of land for the purpose of the maintenance and enhancement of the quality of water in water bodies and coastal water". This gives regional councils sound legal justification to include the regulation of non-point source of pollution in their regional plans and consent processes.

The barriers to management of non point sources of nutrients are then not with the RMA but the implementation of regulation at national and regional levels. Section 30 (1.c.ii) of the RMA has rarely been used for several reasons. Controlling what land can be used for is seen to impinge on the property rights of landowners (Petch et al., 2003). Getting scientifically based policy around diffuse pollution sources into regional plans has met with political and practical barriers (Milne, 2008). Public awareness of the scientific link between water quality and land use and development has only recently surfaced (Edgar, 2008; Parliamentary Commissioner for the Environment, 2006). Models and management tools which illustrate the link specifically to the New Zealand environment have also only recently been developed and applied (Cullen et al., 2006; Petch et al., 2003).

2.5 Conclusion

The expansion of the dairy industry has resulted in an increase in nutrients lost off land to water which has had detrimental impacts on water bodies. Improving the management of nutrients on farm has become a key focus for regulatory bodies, the New Zealand public and the dairy industry (DairyNZ, 2009b; Joy, 2011; McDowell et al., 2009; Wilcock et al., 2007). Non-point source nutrient loss in particular is a major contributor and it appears that the RMA (1991) has thus far been unsuccessful at effectively managing this. DairyNZ believe that there is a need for more effective management of nutrients and that nutrient benchmarks will help to achieve this. The following chapter begins with two case studies of nutrient management in Lake Taupo and Lake Rotorua catchments which demonstrate that nutrient management can be successful. Nutrient management in these catchments has been developed using RMA processes but are a step up from the usual processes discussed in this chapter.

Chapter 3 Nutrient management in New Zealand

3.1 Introduction

This chapter focuses on nutrient management that is outside the status quo regulation typical of New Zealand regional councils described in the previous chapter. It begins by describing the collaborative approach used to regulate Lake Taupo and Lake Rotorua; two iconic North Island lakes which have suffered environmental damage due to non point source pollution. Nutrient management through current dairy industry initiatives is discussed as an alternative approach to government regulation. This discussion highlights the need for a target which indicates what good nutrient management looks like regionally. Nutrient benchmarks, which are the focus of this research, are presented as a potential solution to this need.

3.2 Nutrient management through the RMA in Lake Taupo and Lake Rotorua

Lake Taupo and Lake Rotorua are situated in the central North Island as illustrated in Figure 3.1. Lake Taupo is New Zealand's largest lake at 620 km². It is 160m at its deepest point. The lake is fed by approximately 30 small rivers which drain a 2,800 km² catchment. It discharges at the north eastern end into the Waikato River. The Waikato Regional Council, or Environment Waikato (EW), is the regulatory authority charged with the protection of Lake Taupo under the RMA (Petch et al., 2003). Lake Rotorua is the largest of the 12 major lakes in the Rotorua district. These lakes are managed by the Bay of Plenty Regional Council, Environment Bay of Plenty (EBOP). Lake Rotorua is 81 km² with an average depth of 10.7 m, much shallower than Lake Taupo. The lake drains a 507.8 km² catchment which contains, among other land uses, 26 dairy farms (Edgar, 2008).

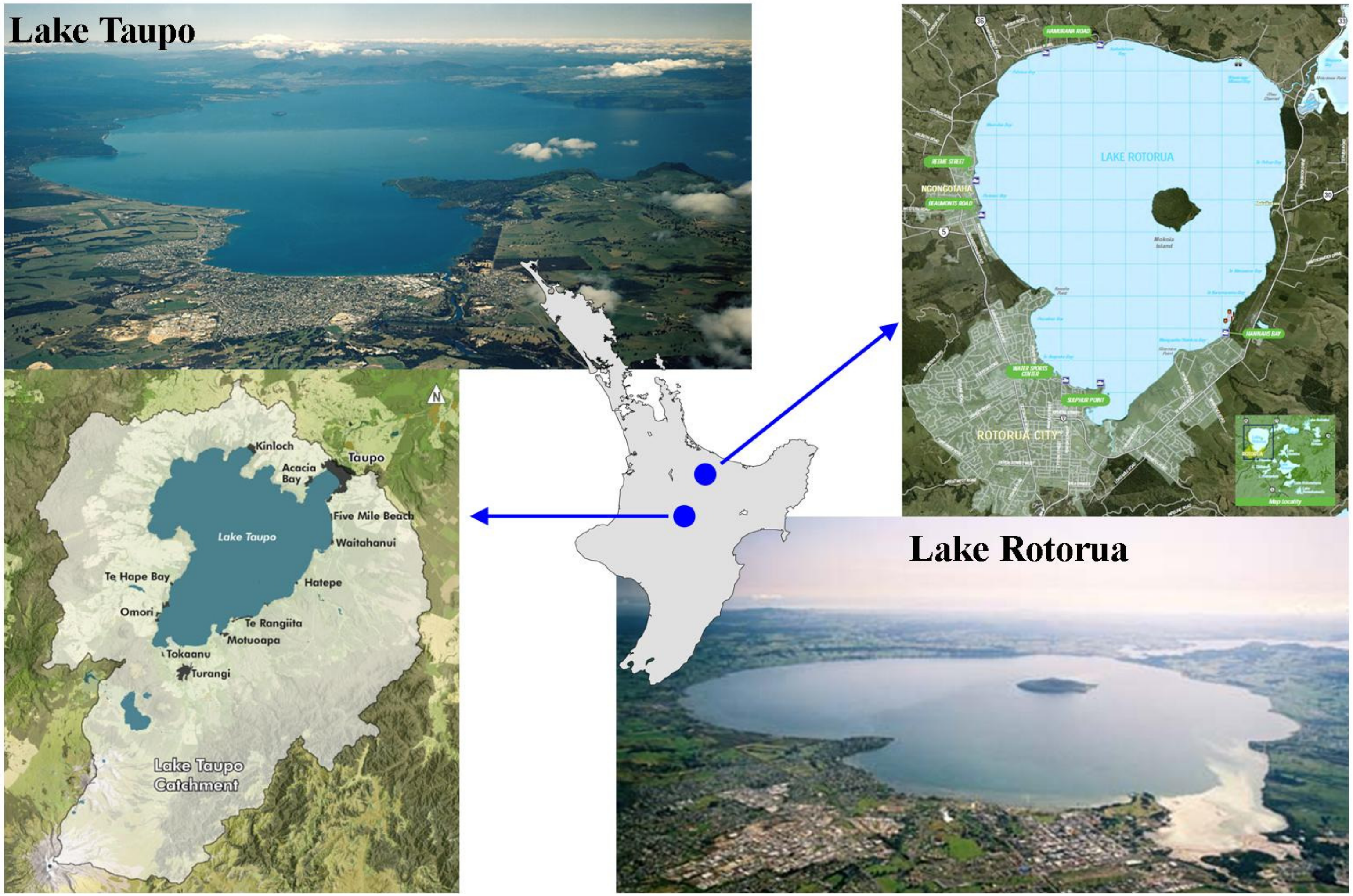

Figure 3.1. Location of Lake Taupo (on the left) and Lake Rotorua (on the right) in the North Island of New Zealand. Adapted from "Lake Rotorua base map" by Environment Bay of Plenty, n.d., http://www.boprc.govt.nz/media/43836/c2219_lakerotoruabase.pdf; "Lake Taupo catchment" by Environment Waikato, n.d., http://www.waikatoregion.govt.nz/; "Taupo" by Geonet, n.d., http://www.geonet.org.nz and "Volcanoes" by Smith et al., nd, http://www.teara.govt.nz/

Both of the lakes are formed as a result of volcanic eruptions. A series of volcanic explosions that began approximately 200,000 years ago in the Rotorua district collapsed the volcano mountain forming a large caldera crater. Lake Rotorua was created as rain water accumulated in the bottom of the caldera (Lakes Management Strategy Working Group, 2000; University of Waikato, 2011). The more recent Oruanui eruption in 181AD also created a large caldera filled with many separate vents. This caldera filled with water over time as well forming the crater lake known today as Lake Taupo (University of Waikato, 2011). Lakes Taupo and Rotorua only partially fill their respective calderas: the townships of Taupo and Rotorua as well as the lake catchments are also located within them. Figure 3.1 shows how Rotorua town is much bigger relative to lake size than Taupo town. The lakes and surrounding catchments make up part of the ancestral lands of the local iwi. Ngati Tuwharetoa and Te Arawa are the recognised tangata whenua and kaitiaki of Lake Taupo and Lake Rotorua respectively. Both iwi applied for guardianship of the lake beds under Waitangi Tribunal claims. Their claims were legitimised giving back guardianship. The iwi are also land owners in the catchments (Edgar, 2008). For these reasons iwi were involved in negotiating plans for the management of the lake.

EW and EBOP have both initiated changes to improve the management of water quality in their respective lakes in the past decade. These changes are focused around controlling the discharge from agricultural land use, particularly non-point source discharge from dairy farms. The theory behind the schemes is similar in each lake but there are differences in the execution which will be explained in this section (Rutherford & Cox, 2009). The lakes have differing water quality characteristics and therefore different water quality aims. Prior to development of the catchments nutrients entering the lake were from natural sources in low volumes. The decline has accelerated as a result of the urban and rural development that has occurred in the catchments in the last 35-50 years. (Burns et al., 2009; Edgar, 2008; Environment Waikato, 2011c; Petch et al., 2003; White et al., 2007). Since then pastoral based farming, particularly dairy, on the porous pumice soils and high rainfall has resulted in nutrients accumulating in surface and groundwater (Edgar, 2008; Environment Waikato, 2011c; Petch et al., 2003).

Lake Rotorua's water quality is poor with high levels of nutrients in both the water and lake bed sediment (Edgar, 2008; White et al., 2007). The Trophic Level index (TLI), which is a measurement of the changes in the nutrient state of lake, indicates that the lake is currently eutrophic. Lake Rotorua tends to be nitrogen limited; the increased nitrate inputs are increasing the nuisance plants. Excessive phytoplankton growth and algal blooms such as toxic blue-green algae as well as anoxic lake waters are usual in the summer months (White et al., 2007). Nutrient levels in Lake Rotorua were jumpstarted as historically the domestic wastewater was discharged into the lake after treatment. In 1991 the wastewater treatment system was updated and the discharge moved to land in a nearby forest. However, the anticipated improvement in water quality did not occur. Nutrients from the wastewater are not all absorbed into the ground and some still enter the lake. Agricultural land use, which includes a large number of dairy farms, is the main contributor in the Lake Rotorua catchment: it accounts for 75% of nitrogen and 46% of phosphorus entering the lake (Parliamentary Commissioner for the Environment, 2006).

Serious consideration to improving the water quality in Lake Rotorua started in the early 1990s when the removal of the wastewater did not significantly improve algal growth. The Lakes Management Strategy Working Group or Rotorua Lakes Strategy Joint Committee, comprised of representatives from EBOP, Rotorua District Council and Te Arawa Trust, produced a management strategy for the lakes in the Rotorua district in 2000 (Lakes Management Strategy Working Group, 2000). In the same year EBOP released their proposed Water and Land Plan. Trophic Level Indexes were set as water quality targets for each lake. These actions did little to appease residents concerned over the state of Lake Rotorua. Their letter to the Parliamentary Commissioner for the Environment (PCE) in 2003 led to an ongoing investigation by the PCE into the effectiveness of planning and management carried out by EBOP.

The Rotorua Lakes Protection and Restoration Programme was formed in 2007 to maintain and improve the water quality of all the Rotorua lakes. It was established under a Memorandum of Understanding between the Crown and the Rotorua Lakes Strategy Group (previously known as the Rotorua Lakes Strategy Joint Committee) (Human Rights Commision, 2009). The programme aim is that "The lakes of the Rotorua district and their catchments are preserved and protected for the use and enjoyment of present and future generations, while recognising and providing for the traditional relationship of Te Arawa with their ancestral lakes." (Human Rights Commision, 2009, para 7)

The Rotorua Lakes Strategy Group has worked and consulted with different sectors of the Rotorua community to develop a management strategy for Lake Rotorua. These sectors include farmers, lakeside residents, iwi groups, fishermen, foresters and lifestyle block owners. The Regional Water and Land Plan (RLWP) became operative in December 2008. Objective 11 of the RLWP contains the desired Trophic Level Index for each of the twelve lakes in the Rotorua district, which includes Lake Rotorua. As the water quality of Lake Rotorua does not meet the proposed Trophic Level Index an Action Plan was created by the Rotorua Lakes Strategy Group to manage the water and land. The overall aim is to reduce the nutrient inputs to the lake by 150 tonnes of nitrogen and 10 tonnes of phosphorus per year (Rotorua Lakes Strategy Group, 2007; White et al., 2007). This action plan is reinforced in the RLWP under Rule 11. High nutrient land use activities are allocated nutrient benchmarks based on nutrient exports between 1 July 2004 and 30 June 2005. This method of allocation is known as grandparenting. A trading scheme exists and property owner can offset nutrient loss on their property elsewhere in the catchment (Environment Bay of Plenty, 2008; White et al., 2007).

In contrast to Lake Rotorua, the water quality in Lake Taupo is good with low levels of plant nutrients and associated phytoplankton in the lake. This helps to maintain the clear blue water the lake is valued for (Environment Waikato, 2011c; Petch et al., 2003; Yerex, 2009). Lake Taupo is nitrogen deficient; this means nitrogen is the nutrient limiting plant growth in the lake. An increase in nitrogen would increase the occurrences of plant growth in the lake. Water quality monitoring data over the past 30 years shows a gradual decline in Lake Taupo's water quality. There is a noted increase in the nitrate-nitrogen amounts at the lake bottom just before mixing occurs in winter. This is evident in the increase in algal growth indicators, nutrient dependent nuisance weed and slime incidences as well several potentially toxic blooms (Edgar, 2008; Environment Waikato, 2011c; Petch et al., 2003).

A major issue with the management of water quality in both these catchments is the time delay in the nutrients entering the lake and tributary surface water bodies. Much of the nutrients from agriculture are leached into the soil at volumes larger than the soil can accommodate. They enter the deep groundwater system where they can have a 30-100 year residence time before entering surface water (Burns et al., 2009; Petch et al., 2003). Up to 80% of the water supplying Lake Rotorua is sourced from groundwater. The result of this attenuation is that recent land use is yet to impact on water quality. Water quality would continue to deteriorate if the current leaching rates were to continue. Even if all leaching were to stop there would still be significant decrease in water quality before any improvements are seen (Parliamentary Commissioner for the Environment, 2006).

The decision by EW to initiate changes to protect the water quality of Lake Taupo arose because of a combination of events in the late 1990's. A State of the Environment (SOE) (1997) report highlighted the impact of agriculture on the environment. It was the first SOE report produced in New Zealand and provided a public source of information which painted an explicit picture of the environment: in particular the impact agriculture had on water quality. The following abstract is one such description from the report.

> "In the course of each year, significant parts of these catchments are defecated on by millions of farm animals, sprayed with fertilisers and pesticides, and rained on. As a result, tonnes of faecal matter, nutrients (i.e. nitrogen and phosphorus), and sediment are washed into surface waters, while nutrients and other contaminants leach into groundwaters."(Taylor & Smith, 1997, p. 37).

The water quality in Lake Taupo in 1999 was good however a monitoring report showed that it was declining at a rate that was "statistically significant". The lake water quality was at risk from the threat of a large increase in land use conversions from pine forests into the more lucrative dairying in the catchment. These conversions would have increased nutrient loads into the lake, and enhanced the impact that agriculture had on water quality in the catchment as described in the SOE (1997) report.

EW was forced to take the unprecedented step of creating a solution, including regulation, to control non-point source discharge in the Lake Taupo catchment (Yerex, 2009).

Tony Petch, Group Manager at EW, said the project to address the nitrogen leaching in the Taupo catchment was a "flagship environmental project" (Yerex, 2009, p. 12). EW consulted with the many different stakeholders in the catchment; Ngati Tuwharetoa, Department of Conservation, Department of Internal Affairs, Taupo District Council, community action groups as well as the local farming community. During the consultation process it became obvious that EW could not continue without the support of farmers. It was also evident that the farmers needed to be proactive and involve themselves in order to protect the lake and the long term viability of their farms. All parties were able to agree that protecting the health of Lake Taupo so that present and future generations can enjoy it was the focus point: because of this constructive discussion, debate and the framework of a solution was able to transpire from the consultation process (Yerex, 2009).

The final link in the solution to manage the nitrogen leaching in the Lake Taupo catchment is implemented in Variation 5 of the Waikato Regional Plan (2011b). High nitrogen leaching land use is an activity which requires resource consent. Nitrogen leaching is capped based on the July 2001-July 2005 nutrient budget data from individual properties (also grandparenting). Nutrient management plans are compulsory to manage ongoing nitrogen leaching on farm (Environment Waikato, 2011c; Land and Water Forum, 2010; Yerex, 2009). Nutrient trading is allowed to maintain flexibility for land use and to reduce the imposition on private property rights. The allocated nitrogen cap is able to be traded amongst other capped land use owners. This means there can be an increase in nitrogen leaching as long as there is a corresponding decrease offsetting it elsewhere in the catchment (Rutherford and Cox, 2009 (Environment Waikato, 2011c). The nitrogen allowance currently sells at around $300-400/kg (Land and Water Forum, 2010). Nutrient caps and nutrient trading are monitored by EW through auditing of nutrient management plans.

The contrasting water quality goals for the lakes create an important difference between the nutrient management capping schemes. Lake Taupo currently has good water quality; the management aim is to maintain this. Due to lag in groundwater flow, water quality would continue to deteriorate if the current leaching rates were maintained. There are nutrients from historic land use which are yet to reach the lake. Nitrogen leaching will be reduced by 20% by 2020 in order to overcome this and allow water quality in lake to stabilise at the desired levels (Environment Waikato, 2011c; Yerex, 2009). To achieve this, the nutrient cap is a fixed target with 20% that will not be allocated to land users by 2020. Lake Rotorua on the other hand has poor water quality. A Trophic Level Index is set that must be reached as part of the Regional Plan to improve the water quality. In order to meet the long term water quality aims in Lake Rotorua the initial nutrient cap will need be reduced in the future.

Public funding of activities via government and councils is also included in both catchments to reduce nitrogen inputs to the lake. The Lake Taupo Protection Trust receives $81 million per year of funding from MFE, EW and Taupo District Council. Part of this funding goes towards purchasing the excess 20% of N allowance which is needed to reach the 20% reduction target in Lake Taupo. This may be achieved by purchasing and converting land to low N discharges or by purchasing a portion of a Nitrogen Discharge Allowance directly off a farmer (Lake Taupo Protection Trust, n.d.). This acknowledges that there are other beneficiaries from cleaning the lake. Making the "polluter pay" would have been counterproductive to the process. Pasture based farmers are unable to foot the bill while running viable businesses. Due to groundwater lag some of the problem is a result of historic behaviour in the catchments. Their pollution is determined to have been unintentional and occurred before the relationship between land use and water quality was understood and explained to farmers (Parliamentary Commissioner for the Environment, 2006; Yerex, 2009).

The previous chapter discussed the difficulty in managing diffuse, or non-point source, nutrient discharges through regional councils under the RMA (1991). The Lake Rotorua and Lake Taupo catchments have provided two case studies where the management of diffuse nutrient sources has been achieved through RMA processes. There is still a lot of work by dairy farmers and regional councils to manage nutrients to improve and maintain lake water quality in the catchments. The complexity and size of these projects physically, scientifically and socially, meant the process has already taken over a decade to complete. One of the keys to the success of these projects was the united desire among all stakeholders to protect their lakes. Not all dairy farming catchments have this to drive a collaborative management process through regional councils. It is also not financially possible to do this in every dairy catchment in New Zealand. The dairy industry has trialled other forms of management to reduce nutrient loss which are outside of the RMA system. This is referred to as industry driven management in this research. The most notable has been the Dairying and Clean Streams Accord (2003) which is an action plan backed by Fonterra (Fonterra, 2003).

3.3 Industry driven nutrient management

3.3.1 Dairying and Clean Streams Accord (2003)

The Dairying and Clean Streams Accord (DCSA) (2003) has been acknowledged as the first formal step to collectively improve the environmental performance of New Zealand dairy farms nationwide (Bewsell et al., 2007; Monaghan et al., 2008). The DCSA was created as a response to public concern over the lack of measures addressing the environmental impacts of dairying and the resulting "Dirty Dairying" campaign led by Fish and Game New Zealand (Deans & Hackwell, 2008; Edgar, 2008; Fonterra, 2003). As Fonterra processes milk from 95% of New Zealand's suppliers it was in an ideal position to back an action plan to improve dairying's environmental performance. This would illustrate that the environment is important to the dairy industry (Fonterra, 2003; Ministry for the Environment, 2011a). It also provided an opportunity for Fonterra to protect the brand image of New Zealand Milk Products in international markets, the value of which will be discussed in Section 3.4.4 National and international reasons to introduce nutrient benchmarks. The DCSA was signed in 2003 by Fonterra, Local Government New Zealand, the Ministry of Agriculture and Fisheries and the Ministry for the Environment. The current DCSA expires in 2012 and a successor is to be announced towards the end of the year (Fonterra, 2011a).

The key purpose of the DCSA is for the collaborators to work together and "reduce the impacts of dairying on the quality of New Zealand's streams, rivers, lakes, groundwater and wetlands" (Fonterra, 2003, p. 1). The DCSA (2003) set a series of actions and five performance targets in order to achieve this key purpose. **Table 3.1** presents these targets, all of which should have 90-100% completion by

2012. The DCSA has implemented some useful initiatives such as the adoption of nutrient budgets and nutrient management plans which have emanated from target 5. While it has not achieved all of the set aims DairyNZ and Fonterra are positive about the DCSA achievements. Both believe that the DCSA is helping to change the attitudes of dairy farmers towards nutrient management (Deans & Hackwell, 2008). As presented in **Table 3.1** positive achievement has occurred. An example is the fencing of waterways, often with the help of regional council funding. The majority of farmers have taken positive steps towards managing nutrient inputs and outputs effectively through implementation of nutrient budgets or nutrient management plans (Edgar, 2008).

Table 3.1. The five performance targets for the Dairying and Clean Streams Accord and the progress that has occurred as at 2012. Adapted from "The Dairying and Clean Streams Accord: Snapshot of progress" by Fonterra, 2011a, http://www.maf.govt.nz/news-resources/publications.aspx?title=Dairying%20and%20Clean%20Streams%20Accord:%20Snapshot%20of%20Progress

Original Target (Fonterra, 2003)	**% of farms and date of completion**	**Progress as at 2012 (Fonterra, 2011a)**
1. Dairy Cattle excluded from streams	• 50% by 2007 • 90% by 2012	84% of relevant streams have dairy cattle excluded
2. Bridging/Culverting regular crossing points	• 50% by 2007 • 90% by 2012	Achieved
3. Fencing Regionally Significant Wetlands	• 50% by 2005 • 90% by 2007	Only Taranaki has achieved this. Tasman, Marlborough and Canterbury Regional Councils have not yet defined regionally significant wetlands
4. Farm Dairy Effluent (FDE) to comply with resource consents and regional plans	• 100% Immediately	69% compliance on average, but varies between 40-95% between regions Major dairy regions: Waikato 66%, Canterbury 65%
5. Having in place systems to manage nutrient inputs and outputs	• 100% by 2007 • Since 2007 Fonterra require NMP on all farms	99% of farms have a Nutrient Budget in place. 46% of dairy farms have NMP's

The failure to achieve target 4, FDE compliance, or measurably cleaner streams has attracted criticism of the DCSA for underperforming, particularly from Fish & Game New Zealand (Deans & Hackwell, 2008). Fish & Game is a non-profit organisation that is funded by the sale of hunting and fishing licences. The organisation is run by Fish & Game councils in regions who are elected by the licence buyers. It was set up in 1990 under Section 26(b) of the Conservation Act 1987 to: "represent the interests of anglers and hunters, and provide coordination of the management, enhancement, and maintenance of sports fish and game resources"(Fish & Game New Zealand, 2012b, para 2). A (2008) Fish & Game report claims that the DCSA has failed to achieve the key purpose of reducing the impact of dairying on water quality. The key criticism is that it focuses on implementing "best practice" and not quantitative water quality benchmarks. Interestingly the targets shown in Table 3.1 while being best practice are also quantitative achievements. The DCSA was never intended to implement water quality benchmarks. It is designed to sit alongside the water quality regulations and objectives in regional plans not dictate or replace them (Jessen & Harcombe, 2008). Regional councils, such as Tasman District, Northland and Taranaki have indeed done this by producing Dairying and Clean Streams Accord based Action Plans.

The large proportion of farmers who still breach farm dairy effluent disposal standards is another common argument against the success of the DCSA (Edgar, 2008; White et al., 2007). However, since the original 2003 DCSA Fonterra has continued to develop initiatives to improve dairying's environmental performance to meet the targets. These initiatives are around the problematic area of effluent compliance in particular. Most recently Fonterra implemented the "Every farm, every year" project. It aims to tackle FDE non-compliance issues through best management practice. "Every farm, every year" involves an annual check of every farms effluent system. These effluent system checks were completed by independent assessors. All 10,500 Fonterra suppliers were checked in 2010/2011 season (Fonterra, 2011a). Fonterra has a team of 13 field officers called Sustainable Dairying Advisors (SDA). Those farmers found to be non-complying or at risk of non-compliance during initial assessments get a follow up checks by SDA, special assistance and a remediation plan (Fonterra, 2010a, 2011a). Failure to resolve the issue can result in fines or ultimately Fonterra not picking up the milk which is tantamount to putting them out of business (Fonterra, 2010a).

3.3.2 Westland Milk Products' Environmental Code of Practice

The DCSA applies to the farmers in the Waikakahi catchment who supply Fonterra. It is not applicable to the Inchbonnie catchment farmers on the West Coast who supply Westland Milk Products (WMP) which is an independent co-operative dairy company. WMP have recently introduced an Environmental Code of Practice (COP) which is an industry based management strategy. The COP was completed as part of WMP efforts to encourage sustainable farming and involves collaboration between WMP and the West Coast Regional Council (Celsias, 2011; Westland Milk Products, 2011). Under the COP WMP will perform environmental health checks on supplier farms, similar to those completed under Fonterra's "Every Farm, Every Year" project. The farms will be assessed against a checklist in the COP (Westland Milk Products, 2011). The checklist includes activities that require resource consent under the West Coast Regional Councils Regional Plan such as effluent disposal, stock crossings and standoff pads. The COP rates non-compliance with consents into three categories: critical, major or minor. Requirements for action and follow up checks are dependent on the level of non-compliance. Persistent non-compliance or failure to resolve non-compliance can lead to WMP discontinuing milk pick up (Westland Milk Products, 2011). The WMP Code of Practice is binding to all suppliers and will be included under the terms and conditions for supply (Westland Milk Products, 2011).

3.3.3 Nutrient budgets and Nutrient management plans

The original DCSA was a voluntary accord and was not legally binding to any of the partners who signed it or the New Zealand dairy farmers (Edgar, 2008; Fonterra, 2003; Jessen & Harcombe, 2008). Target 4 regarding farm dairy effluent compliance was already a legal requirement under regional council regulations. Nutrient budgets became requirements for Fonterra suppliers in the 2006/2007 season, failure to provide a budget to Fonterra field officers two seasons in a row may incur a penalty (Fonterra, 2007). Nutrient Management Plans have also been requirements since 2007 but as yet no penalties are incurred for not possessing one (Fonterra, 2011a). Under Westland Milk Products

Environmental Code of Practice (2011) nutrient budgets will be checked and nutrient management plans will need to be sighted during the environmental health checks of supplier farms. Persistent failure to provide them may sustain penalties.

Nutrient Budgets quantify all nutrient inputs and outputs from an agricultural system (Dairy Australia, 2008; O'Connor et al., 1996; Waikato Farm Environment Award Trust, 2002). They assess nutrient losses against required inputs to keep the system balanced (O'Connor et al., 1996; Waikato Farm Environment Award Trust, 2002). Inputs to farm systems include: fertiliser, brought in feed, clover nitrogen and farm dairy effluent. Outputs include: product, nutrient retained in soil, gaseous losses to the atmosphere and transfers to non-productive areas such as waterways or races (Waikato Farm Environment Award Trust, 2002).

The concept of nutrient management planning evolved from nutrient budgets in intensive European and American agriculture systems. There it was found that they had surplus phosphorus in their systems and needed more tools alongside their nutrient budgets to help manage this so developed NMP. NMP are based on nutrient budgets and use nutrient models to derive their data. The relationship between the two is depicted in Figure 3.2. A nutrient budget only records nutrient inputs and outputs whereas a NMP is a written plan which describes how nutrients will be used on farm to minimise losses. A farm systems approach is employed within the NMP; they include nutrient budgets as well as soil tests, effluent applicator rate tests and effluent analysis. NMP ascertain current farm management practices and summarise whole farm goals for the year. They include pathways to reach the goals. NMP aim to maximise profit value from nutrient inputs while avoiding or minimising adverse environmental impacts (New Zealand Fertiliser Manufacturer Research Association, 2007).

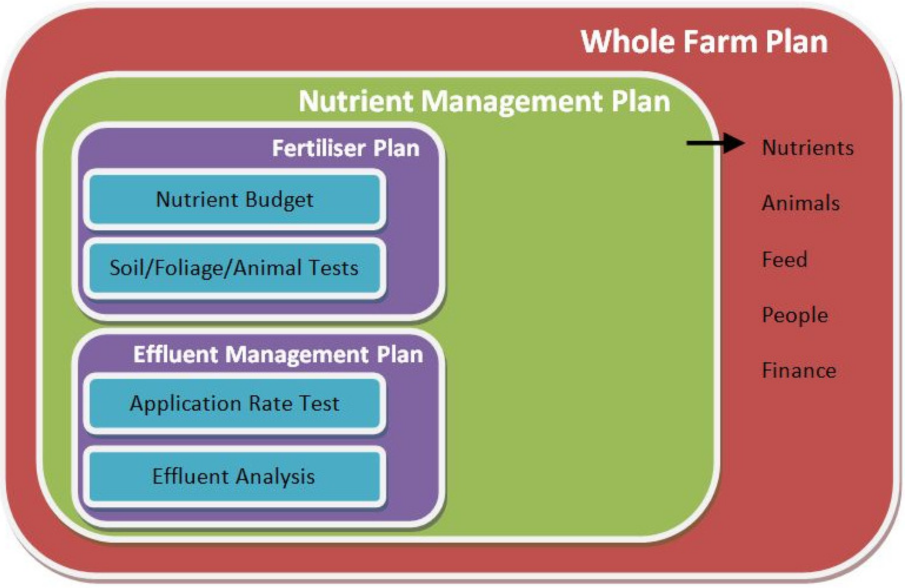

Figure 3.2: Simplified diagram showing how Nutrient Budgets, Nutrient Management Plans and Whole Farm Plans are related. From "Nutrient Management Plans: A tool to improve Resource Use Efficiency" by J. Chan, 2011, DairyNZ discussion paper.

The Code of Practice for Nutrient Management written by the New Zealand Fertiliser Manufacturer Research Association (2007) guides the design of nutrient budgets and NMP. Nutrient budgets and NMP are written in accordance with this code by the fertiliser consultants who service the dairy farms in consultation with farm managers. The fertiliser consultants have completed a recognised training program in sustainable nutrient management at Massey University to become accredited nutrient advisors. Nutrient budgets are also internally and externally audited (New Zealand Fertiliser Manufacturer Research Association, 2009). Fertiliser companies use nutrient budgets to guide their customer's fertiliser purchases.

The value of nutrient budgets and therefore NMP's has come under scrutiny. Bryce Johnson, Chief Executive of Fish & Game New Zealand (2009) claims that the nutrient budgets Fonterra dairy farms have are useless. "Having a nutrient budget is like having diet plan, and of equal use if it's not implemented" (Fish & Game, 2009, p. 1). DairyNZ acknowledges that nutrient budgets and NMP currently only provide an explanation of how each individual farm is performing. Farmers have nothing to quantify their practice or impacts against. This is the case even in the BPDCS where education on the links between practice and water quality has been a focus. Previous qualitative research on the opinions of New Zealand dairy farmers found that there is a gap between the farmers perception of how effectively they deal with water quality issues and the reality of this (White & Wilson, 2007). A recent perception survey by Mackay & Smith (2010) determined that the majority of BPDC farmers believed that effluent management held the greatest risk to water quality, as opposed to land use intensity and nutrient loss which is arguably the bigger concern (Scarsbrook, 2011a). It seems likely that the lack of water quality or nutrient management benchmarks in New Zealand is partially driving this gap in farmer knowledge.

There is a real need for tools that improve nutrient management by providing farmers with an explanation of what is acceptable or achievable in their region. Current thinking within the dairy industry is that the introduction of nutrient benchmarks would achieve this. Fonterra environment programme manager Charlotte Rutherford, in a recent *Inside Dairy* article, said benchmarks will be beneficial because at the moment farmers are unsure if their practice is good bad or mediocre (DairyNZ, 2011c). Nutrient benchmarks are the main focus of this research and will be explored in the following section.

3.4 Nutrient benchmarks

3.4.1 Explanation

Nutrient benchmarks are a quantitative target for nutrient loss or nutrient use efficiency. They aim to be an achievable nutrient management target to work towards. The benchmark will guide good nutrient management and increase nutrient use efficiency for each particular region (DairyNZ, 2010a). There will be three types of nutrient benchmarks: nitrogen conversion efficiency (%), which indicates how efficiently the farm converts external nitrogen inputs such as feed into nitrogen contained in product such as milk; nitrogen leaching loss (kgN/ha/yr), which is the amount of nitrogen leached and lost from the farm from soil and drainage water below the plant root system; and phosphorus loss (kgP/ha/yr), which is an estimation of the amount of phosphorus lost from the farm via surface runoff (Chan, 2011; DairyNZ, 2011b).

3.4.2 Development

The benchmarks are set as a target for the dairy industry to achieve in the Dairy Industry Strategy: Direction to the Vision (2010a). This document was written after DairyNZ's Strategy for New Zealand Dairy Farming (The Strategy) (2009b) which is a guide for the investment and activities of the industry until 2020. It sets five outcomes for the industry. The Direction to the Vision (2010a) is a set of targets to help achieve the outcomes. Target 14 is:

> "By end of 2011, 50% of dairy farms have, and are implementing through an auditable process, nutrient management plans that reduce their nutrient footprint either to established benchmarks of high resource use efficiency or agreed partnership targets; 90% of farms are doing so by end of 2012." (DairyNZ, 2010a, p. 25)

According to the Strategy to the Vision, in the major dairy regions local authorities are setting nutrient loss targets to improve nutrient management. The benchmarks will be developed by the dairy industry in consultation with these local authorities. This is consistent with industry management under the DCSA which believes that industry self management of issues is more likely to achieve environmental best practice than government based regulation alone (Fonterra, 2003).

The benchmarks will be agreed partnerships between regional councils and the dairy industry. They will be developed to take into consideration the nutrient loss target the regional councils are setting and their achievability. DairyNZ hopes the benchmarks may be accepted in lieu of regulatory targets. There is some concern that regional councils may take the benchmarks and enforce them as a minimum standard. Regional councils are only considering imposing targets at this stage (Scarsbrook, 2011b). However the Strategy is dated until 2020 and it seems unlikely that by then relevant authorities would not have nutrient loss and water quality targets in place throughout New Zealand. The benchmarks will therefore be designed to be achievable so inclusion in regional plans would not be too concerning (Chan, 2010). In these regions with agreed partnerships, the regional councils and milk companies will be responsible for ensuring appropriate nutrient management plans that reach the set targets are produced.

In the regions without agreed partnerships the focus will be on improving nutrient efficiency to a benchmark which is achievable in the region. The fertiliser companies, who produce the NMP, as well as milk companies and DairyNZ will ensure the NMP are suitable for the regions. It seems likely that the improvement in water quality will be less in these regions because the measure of suitability is determined solely by the dairy industry and based on boosting efficiency not reducing negative environmental outcomes.

3.4.3 Implementation

The nutrient benchmarks will be implemented in the Inchbonnie and Waikakahi best practice dairying catchments (BPDCs) first. The farms in the BPDCs will undergo whole farm monitoring. The views of the farmers on the benchmarks, the economic impacts on the farms and the effects on water quality will be observed by DairyNZ. Lessons learned from the implementation in the BPDCs will be used to roll this programme out nationwide.

The two BPDCs both have degraded water quality as a result of dairy farming in the catchments as described in Section 1.4. The nutrients that are of concern differ between the catchments. The Inchbonnie catchment is a tributary of Lake Brunner so nutrient management in the catchment is focused on the impact it has on the lake. Lake Brunner is phosphorus limited so controlling the amount of phosphorus entering the lake is the key management strategy (McDowell, 2010; Wilcock & Duncan, 2009). As a result the Inchbonnie catchment will have a P loss benchmark (DairyNZ, 2011b). Nitrate concentrations in the Waikakahi stream are the main nutrient concern in the Waikakahi catchment. These lead to an increase in plant growth which reduces drainage in the streams as well as the potential for toxicological effects on sensitive species (Meredith et al., 2003). The Waikakahi catchment will have a N loss benchmark to reduce the nitrate concentrations in the stream (DairyNZ, 2011b).

The benchmarks will be implemented through inclusion in NMPs. The farm systems approach which is employed within the NMP's illustrates where excess nutrients are being lost from the farm system. Nutrient benchmarks will guide farmers to where they should be in regards to nutrient management and loss. Farmers are required to set goals within their NMP for their business, they may be related to any aspect of the business such as ensure all staff have first aid certificates. How each farmer will achieve the nutrient benchmarks is intended to become included as part of farmers' goals. For example this may include completing fencing off waterways or installing a wintering shed (Chan, 2010).

3.4.4 National and international reasons to improve nutrient management through the introduction of nutrient benchmarks

So far the discussion has focused on improving nutrient management from an environmental perspective: reducing nutrient loss improves water quality in New Zealand. But there are other reasons driving the dairy industry to implement initiatives, such as the Dairying and Clean Streams Accord and nutrient benchmarks, which come at some financial cost to dairy farmers. This section will discuss the national and international reasons that are ultimately driving the need for nutrient benchmarks in New Zealand.

National reasons to introduce benchmarks

Basil Chamberlain, Chief Executive of Taranaki Regional Council, argued at the 2008 Dairy Summit that ideally New Zealand should achieve world class environmental water resources as well as world class dairy production (Chamberlain, 2008). Achieving the two simultaneously presents a challenge. There is plenty of evidence that achieving world class dairy production is ruining the world class water resources which were reasonable good in most places pre-dairying. A Ministry for the Environment report (2009) analysed water quality in 14 dairy catchments located throughout New Zealand and found that water quality was degraded in these catchments. Nitrogen levels in thirteen out of fourteen catchments exceeded guidelines for nuisance periphyton growth and P levels in half the catchments exceeded guidelines for nuisance periphyton growth (Ministry for the Environment, 2009). The most recent report on lake water quality in New Zealand (2010) found 32% of the 4,000 lakes in New Zealand over 1 hectare in size are likely to have poor or very poor water quality. These lake tended to be surrounded by pastoral land cover (Verburg et al., 2010). There is growing public concern about the impact of dairy farming on water quality and it is the main driver behind the national reasons to introduce nutrient benchmarks in New Zealand.

The public concern is reflected in recent local and national government policies (Chamberlain, 2008; Deans & Hackwell, 2008). It is also reflected in the media exacerbated "dirty dairying" perception. The "dirty dairying" campaign was started by a Fish & Game New Zealand report in 2001 about the impact that the intensification of dairying has had on freshwater quality. The New Zealand media have adopted the phrase and ten years later still use it in headlines as if it describes an actual farm practice. Recent headlines include "$51,000 in fines for dirty dairying" ("Fines for Dirty Dairying", 2012) in this headline dirty dairying means effluent discharge into waterways, and "Another rise in 'dirty dairying'" (Otago Daily Times, 2011) in this headline dirty dairying refers to not all of the DCSA targets being reached.

Peer reviewed research into how New Zealand public perceive dairying and the environment is currently limited. A Lincoln University survey asks 2000 people biennially about their perceptions of the state of the New Zealand environment and its management. The 2004 survey asked whether the respondents believed that water quality in lowland streams was affected by dairy farming in their region. It found that on average 39% of the respondents believed it had (Hughey et al., 2004). The most recent survey (2010) did not ask this specific question. When asked what the most important environmental issue in New Zealand was the majority of the respondents (24%) identified water pollution and/or water (unspecified).

Both the 2004 and 2010 reports on the surveys draw attention to the fact that it is unclear how these opinions have been formed (Hughey et al., 2004, 2010). It may be that the increase in regulation and media interest courtesy of the "dirty dairying" campaign has increased public awareness as opposed to the other way around. It is not only adversary or regulators of the dairy industry acknowledging that there has been an increase in public concern, regardless of how it has arisen. John Penno, Chief Executive of Synlait, a Canterbury milk production company and John Hutchings, General Manager of Sustainable Production at Fonterra, are two prominent figures within the dairy industry who have said that the New Zealand public currently have a negative opinion of the dairy industry (Hutchings, 2010; Piddock, 2011). It is also acknowledged within the Strategy for New Zealand Dairy Farming (2009b) which was developed with input from DCANZ, Federated Farmers and thousands of dairy farmers.

If satisfactory improvements are not made in fixing the environmental degradation caused by dairy farming the reputation of dairying will continue to deteriorate. If this occurs, public concern may grow enough to support the implementation of restrictive controls into regional plans. This effectively limits both dairy farmers' license to operate in their areas and the industry's ability to grow in New Zealand. It will lead to constraints on operation, farm practice variability and production growth; in addition to increases in compliance and regulatory costs (Hutchings, 2010; Scarsbrook, 2011b). The New Zealand pasture based farming system is internationally unique. It creates a marketable point of difference for Fonterra's New Zealand milk products. Fonterra would like to continue to farm here for that reason despite being able to source milk overseas at less cost (New Zealand Dairy Industry, 2011; Parliamentary Commissioner for the Environment, 2004). In order to continue dairy farming in New Zealand environmental concerns, such as nutrient management, must be adequately addressed.

International reasons to introduce benchmarks

New Zealand markets itself to the rest of the world as clean, green and 100% Pure (Hutchings, 2010; Land and Water Forum, 2010; Pearce, 2009; Salmon & Joy, 2011). This image is a valuable part of New Zealand's domestic and international tourism industry. The 100% Pure brand was estimated to be worth US $13 billion in 2005 by Interbrand, one of the world's largest brand consultancies (Tourism New Zealand, 2009). New Zealand uses this image to promote its dairy product trade (Land and Water Forum, 2010; Pearce, 2009). The clean, green image of New Zealand is beginning to waver as the reality of the environmental impact expansion and intensification of the agricultural sector has had becomes apparent. New Zealand's promotion of a clean green image has been described by Pearce (2009), a writer for *The Guardian* as a "most shameless two fingers to the global community" (Pearce, 2009, p. 1). Prime Minister John Key struggled to defend the 100% Pure image in an interview with BBC's Stephen Sackur. When questioned about it his answer was an unconvincing "for the most part, I think, in comparison with the rest of the world, we are 100% Pure" (Prime Minister John Key 9 May 2011 BBC, 2011). The international reasons to introduce nutrient benchmarks focus on rebuilding and maintaining this image. It will be important in helping New Zealand products, particularly dairy, maintain a competitive market edge both now and in the future.

There is increasing indications in national and international media, as well as in industry reports, that consumers are becoming more aware of the environmental footprints of their food and retail products ("Agri-Food Sector Assess Footprint", 2009; Bay of Plenty Times, 2011; DairyNZ, 2009b; Hutchings, 2010; "Retailers-Food Industry Sustainability Pledge", 2009). Value is being placed on whether environmental credentials, such as water quality and quantity, resource efficiency and waste reduction, result in a product that is environmentally sustainable (Fonterra, 2003; Hutchings, 2010; "Retailers-Food Industry Sustainability Pledge", 2009). European retailers are working together within the EU to focus on increasing the sustainability of food products and consumer awareness. Action plans have been adopted by the European Commission on Sustainable Consumption and Production (SCP). The group has the backing of the Consumer Protection Commissioner and Confederation of EU Food and Drink Industries ("Retailers-Food Industry Sustainability Pledge", 2009). They expect to have a framework assessment methodology for food and drink products finalised by the end of 2011. When implemented this will provide accessible information on the products lifecycle and will allow consumers to make informed decisions when purchasing ("Agri-Food Sector Assess Footprint", 2009a). It may set a precedent for other consumer groups. This shift from a market focused purely on the quality of the end product to one with an eye on farm environmental practices as well welcomes the advent of nutrient benchmarks in New Zealand. The benchmarks would provide a means of gaining good sustainability credentials during the primary production stage of New Zealand milk products lifecycle.

The introduction of benchmarks is important for the international future of the New Zealand dairy industry. Milk production in New Zealand is currently based on a commodity market (Bay of Plenty Times, 2011). This means that all farmers get paid the same price per kilogram of milk solids regardless of what farming practices they employ. The price of New Zealand milk solids is influenced by the price overseas producers are getting for their similar products. The abolition of EU milk quota in 2015 will mean there is no limit on milk production in EU countries as currently. This coupled with removal of EU subsidies will most likely lead to instability in the international market (Westland Milk Products, 2010) which is described in Section 2.2.2 International dairy market. It is also likely that it will lead to intensification and expansion of dairy production in several EU areas (Jongeneel et al., 2010). The EU and parts of the rest of the world can already beat New Zealand on commodity price as their land and labour costs are much less (Joy, 2011). The challenge for New Zealand will be to trade on our clean green image and develop a market for premium sustainable milk products which are still profitable (Bay of Plenty Times, 2011; Hutchings, 2010; Joy, 2011). It is here that the nutrient benchmarks will be valuable. If sufficiently audited they will enable quantitative differentiation between milk produced via high nutrient management standards and milk produced with poor standards. It will certify them as a quality product for international buyers.

3.5 What is a sustainable milk production system?

Chapters 2 and 3 have framed conceptually the context in which this research will sit. They have illustrated that there is a need for holistic nutrient management in New Zealand. It has been achieved in Lake Taupo and Lake Rotorua under the RMA but the process is lengthy and not every catchment will have effective drivers to gain stakeholder support. Current dairy industry initiatives, such as the DCSA, have improved some aspects of nutrient management but not all. Nutrient benchmarks will set targets for nutrient loss or nutrient use efficiency which will be achieved through improvement of all aspects of nutrient management on farms. The main aim of this research is to determine if these nutrient benchmarks will help achieve sustainable milk production systems. In order to answer this question a definition for a “sustainable milk production system” must first be established.

Sustainability and having a sustainable dairy industry are key concepts that have emerged during the conceptual context of this research. They are used by regulators or opponents to the dairy industry as well as dairy industry stakeholders. The promotion of the sustainable management of natural and physical resources in New Zealand is presented as the main purpose of the RMA (1991). Advocating for sustainable farming practices is one of the functions performed by Fish & Game New Zealand in order to protect the habitat of fish and birds (Fish & Game New Zealand, 2012a).

Examples of the use of the sustainability concept within the dairy industry include Fonterra having a team of sustainability advisors to manage effluent compliance by its suppliers as well as DairyNZ having sustainability as one of their three key business aims. At the 2010 World Dairy Summit in Auckland leaders from the International Dairy Federation (IDF) claimed that sustainability of the dairying sector will be the defining issue of our time ("World Dairy Summit in NZ", 2010). The IDF is an alliance of global dairy industry stakeholders based out of Brussels which focuses on scientific expertise for the worldwide dairy industry (International Dairy Federation, nd; "World Dairy Summit in NZ", 2010).

As a geographer the definition of sustainability the researcher is most familiar with is the RMA definition of sustainable management which is derived from the United Nations Brundtland Commission (1987) definition of sustainable development (McChesney, 1991). Sustainability is the ability to meet the needs of the present without compromising the ability of future generations to meet their own needs. Consistent with this, Le Heron and Gray (2010) developed a stylized place-centred framework of sustainability illustrated in Figure 3.3. It was developed to consider sustainability of the dairy industry using knowledge from outside the industry. The key message from the figure is that the definition of sustainability is dependent on the value the place has to the community: economically, environmentally and socially/culturally. The dairy industry definitions of sustainability that are promoted on their websites do not include the place centred concept. Rather they focus on sustainability being a balance between profitability and environmental responsibility (DairyNZ, 2011a) or between the environment, economic and social sustainability (Fonterra, 2011b). These definitions are still similar to the RMA (1991) definition.

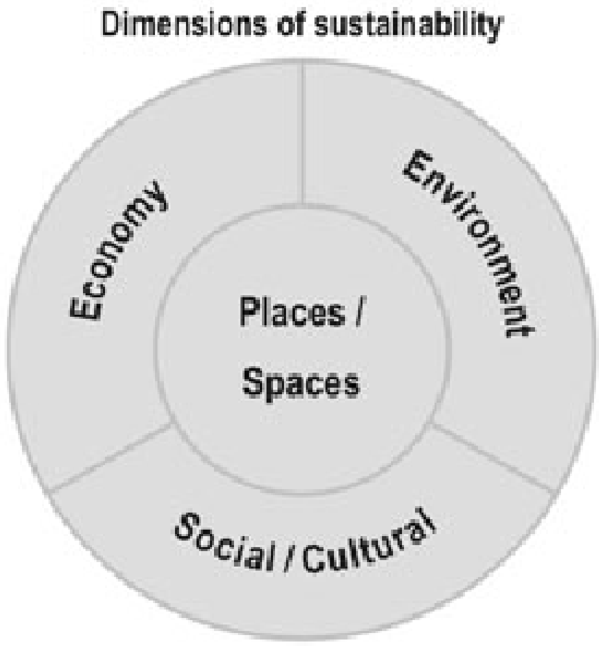

Figure 3.3: A geographic overview of the dimensions of sustainability. From "Globalising New Zealand: Fonterra Co-operative Group, and shaping the future", by S. Gray and R. Le Heron, 2010, New Zealand Geographer, 66, p.5.

The nutrient benchmarks will be determined region by region which is consistent with them helping to achieve a place centred concept of sustainability. The environmental, economic and social/cultural value of places and spaces throughout New Zealand varies within regions and catchments. The benchmarks will also vary, reflecting these differences. The Inchbonnie catchment will have a P loss benchmark because in that place P is the nutrient affecting environmental and social values by threatening Lake Brunner's water quality. The Waikakahi catchment on the other hand has different environmental and social values and will not have a P loss benchmark. Whether or not this approach is sustainable in the future will be discussed in Chapter 6.

For this research a sustainable milk production system is one that is able to meet the current economic (or production) needs of the farmer and New Zealand as well as the social/cultural and environmental values of the place the system is located in. It achieves this while enabling future generations of dairy farmers and New Zealanders to benefit from the economic, social/cultural and environmental values. The research presented in this thesis will both draw on and add to the current knowledge around nutrient management and benchmarks to determine if the nutrient benchmarks will achieve sustainable milk production systems in New Zealand.

Chapter 4 Methodology

It was stated in Chapter 1 that the main aim of this research is to determine if nutrient benchmarks will help achieve sustainable milk production systems in the two contrasting catchments. The first question, regarding what is meant by sustainable milk production systems, was answered in Chapter 3. This chapter presents the mixed method approach used to answer the remaining two research questions:

- How do dairy farmers in the two Best Practice Dairy Catchments interpret the nutrient benchmarks?
- How effective are the benchmarks in managing nutrient loss and improving water quality in the two Best Practice Dairy Catchments?

It is split into the methodologies that relate to the individual research questions. A mixed method interview is used in this research and is presented in Section 4.1. The data will be coded to generate themes for discussion which will establish how dairy farmers interpret the nutrient benchmarks. Quantitative water quality modelling is used to determine the effectiveness of the benchmarks in managing nutrient loss and improving water quality and is presented in Section 4.2.

4.1 Farmer interviews

Ultimately it is the dairy farmers who have to understand and implement the benchmarks for them to be of any benefit. Therefore the achievement of sustainable milk production systems through benchmarks is partially dependant on how dairy farmers interpret them. This is the basis for the second research question. Several qualitative methods were considered for use to answer this question. These methods included focus groups, face-to-face interviews, electronic surveys and telephone surveys. Focus groups were ruled out as attendance is generally low in dairy farm catchments. This is because there are a number of meetings about all aspects of the farm business, such as staff management or animal welfare, which occur monthly in the catchment. Farmers tend to prioritise and attend important meetings instead of all meetings. Mail or electronic surveys are relatively cheap and quick to implement. These were dismissed as the response rate for an unsolicited mail survey is low unless the respondents are highly motivated (Fink et al., 1995; McGuirk & O'Neill, 2005; Parffit, 2005). Electronic survey response rate is affected by age, class and gender (McGuirk & O'Neill, 2005). Past experience has shown DairyNZ that dairy farmers are unlikely to participate in online surveys (S. Hayward, personal communication, 27 October, 2010). Telephone interviews were administered as they have good response rates (McGuirk & O'Neill, 2005). They avoid expense and time for the Christchurch based researcher and can be replicated at a later date in the same catchments (Creswell, 2009). The researcher was introduced to the farmers in a catchment newsletter as well as by DairyNZ staff in farmer meetings which avoided cold calling.

There are two approaches that can be employed in interviews: quantitative and qualitative. Quantitative interview questions are structured and have a limited range of answers. They focus on cause and effect. These questions have variables that can be measured or quantified so statistical analysis can be applied. Qualitative questions are open ended and are designed to explore the meaning that participants give to an issue or problem. They are usually associated with an interview style and provide more in-depth answers than quantitative questions. A mixed method approach, as used in this interview, employs a combination of both qualitative and quantitative questions. This provides a more comprehensive understanding of the research problem than implementing a single method would (Creswell, 2009; McGuirk & O'Neill, 2005).

The BPDCs have been the sample area for many industry surveys. Care was taken during survey development to ensure the questions were relevant to current projects in the catchments and do not repeat questions that have recently been asked before. Simon Sankey, Regional Team Coach for DairyNZ's consulting officers in Canterbury, has found that this increases response rates (personal communication, 22 June, 2011). Pretesting of surveys is essential as it scrutinises the questions and format allowing any shortcomings to be fixed before the questionnaire is distributed (Hesse-Biber & Leavy, 2006; McGuirk & O'Neill, 2005; Parffit, 2005). The interview was pretested on DairyNZ staff who have both academic and practical dairy knowledge. From the pretesting the tone and flow were able to be appropriately adjusted.

The survey consisted of a series of questions split into three main sections. The first section is demographic information. This section comprised of closed questions which provide an overall picture of the participants for analysis purposes. The responses can be compared to previous surveys to determine how representative of the catchment the sample is (Hesse-Biber & Leavy, 2006). This section has been located first as answering such questions builds up the respondent's confidence in his or her ability to answer the survey (Hesse-Biber & Leavy, 2006; S. Sankey, personal communication, 22 June, 2011). It also builds up the interviewer's confidence and develops a rapport between interviewer and respondent.

Nutrient benchmarks will be included in nutrient management plans (or farm plans in Waikakahi) as illustrated in Figure 3.2. Therefore, an understanding of nutrient management, both the general concept and specifically on their farm, is needed by the farmers. The second section focuses on farmers' understanding and opinion of nutrient management. The third section concentrates on understanding and opinion of the nutrient benchmarks: whether farmers think they would find them valuable and what would encourage them to meet them. These sections contain a mixture of open and closed questions. Rating scales are used to ask subjective questions. There is then a request for an explanation of the rating. This allows the opinion to be compared numerically while also providing a more in-depth understanding of the opinion. It also allows elaboration on closed questions which may not be an exhaustive list of the available options (Brace, 2008; Iarossi, 2006). A copy of the interview format is provided in Appendix 1.

Before this survey was implemented a research proposal was developed. A low risk ethics application was made to the Department of Geography at the University of Canterbury. This was granted and forwarded to the University of Canterbury Human Ethics Committee. The Chair of the Human Ethics Committee supported the departmental approval on the 26/11/2010. The research was assigned with the following reference 2010/87/LR. The initial approval was for face to face interviews, this method was abandoned due to cost and timings. On 08/07/2011 the researcher was given amendment approval to change the survey distribution method to telephone interviews.

Selection for the survey was dependent on being a dairy farmer in a BPDC. All 18 BPDC dairy farmers were invited to participate. Farmer names and phone numbers were provided by DairyNZ. There was only one occasion where the name on the list was not the appropriate person to answer the questions. This was resolved as the farmer on the list, who was the owner, directed the researcher to the manager. In total eleven interviews were conducted. Three were from the Inchbonnie catchment and eight from the Waikakahi catchment. Out of the remaining seven farmers, one refused and six were never available to complete an interview. The answers each participant gave were recorded verbatim and transcribed by the researcher. Recording verbatim allowed the researcher to perform interviews at any time without restrictions that would come with hiring equipment to record telephone interviews. It did provide the potential to introduce human error through misreporting or missing words, phrases or answers. This was minimised by the use of personal shorthand.

The quantitative responses for the demographic and rating scale questions were entered into an Excel spreadsheet. Simple statistical analysis was performed to determine minimum, maximum and average responses for the catchments. The quantitative results are presented in Chapter 5 as graphs and tables. These figures allow the results from the Inchbonnie catchment to be readily compared against those from the Waikakahi catchment to ascertain broad similarities or differences.

The qualitative data in the transcripts was hand coded by the researcher. The purpose of coding is to reduce data, organise it in a logical system and enable exploration, analysis and building of themes (Cope, 2005). There are two broad types of content separated during coding. These are manifest messages, which are obvious, similar to the surface structure of the questions, and latent messages which have a deeper meaning or emerge from beneath the surface of the question (Cope, 2005; Creswell, 2009). Responses to each question were mapped out in a hierarchical tree illustrated in Figure 4.1. Each question is represented as a node. Direct responses, which were treated as manifest messages, are represented as sub nodes below the question. Emerging content was treated as latent messages. They were added as a separate node when they occurred.

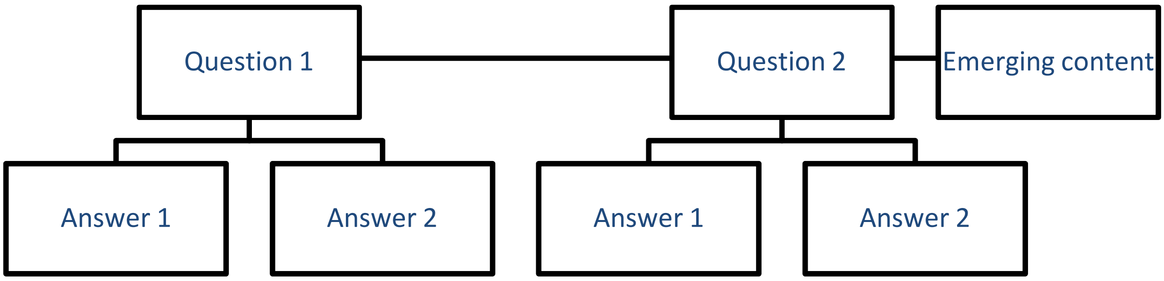

Figure 4.1. Coding system used to analyse the qualitative survey responses. The top row illustrates the primary nodes which represent the interview questions as well as content that emerged without direct questions. The second row illustrates the secondary or sub-nodes which consist of the answers given to the questions. The use of the charts provides the researcher with a visual to organise and link the answers into themes for discussion.

Initial themes were pre-empted through background research and during the development of the survey aims and questions. Organising and analysing the transcripts into the map structure was used to determine whether these key themes were present in the interviews. Sub-nodes and nodes from the map were combined where appropriate to form themes or develop new themes where needed. The themes established during coding are presented in Chapter 5, alongside the appropriate quantitative figures.

4.2 Water quality modelling

Geographic Information System (GIS) based water quality modelling was used in this research to determine if the nutrient benchmarks would improve water quality therefore answering the third research question. This is important to the main research aim: even if dairy farmers positively interpret the benchmarks they will not achieve sustainable milk production systems if they do not sufficiently improve water quality. Water quality models in New Zealand are generally used by regional and unitary authorities to help fulfil their responsibilities under the RMA (Fenton, 2009). Their results are used to manage flooding, sediment loads and water yields. The most recent focus is on developing models to assist in managing non-point source nutrient losses (Fenton, 2009). The use of these models is predominantly based around assessing the effects of current and proposed land use on water quality. Water quality models can also be used to determine the magnitude of management changes required to meet specific water quality targets (Fenton, 2009). Models and their results provide an instrument for scientists to interact and influence policy throughout the development process (Fenton, 2009; Wainwright & Mulligan, 2004). The majority of the research for the models used in New Zealand is completed through Crown Research Institutes (CRI) such as NIWA and AgResearch.

CLUES (Catchment Land Use for Environmental Sustainability) is the GIS based water quality model used in this research. The latest version of CLUES (v. 3.1) was chosen as it is designed specifically for the New Zealand environment and is the most popular model of its type out of the limited range available in New Zealand (Elliott et al., 2011). The CLUES model was run using two scenarios. The first scenario predicted the current water quality. This was compared to the measured current water quality. Accuracy of CLUES predictions for the catchments was determined by whether or not these values agreed. The second scenario predicted changes in the water quality if the nutrient benchmarks were achieved. The significance of this change was determined by comparisons with appropriate water quality guidelines. The two scenarios were also run on the catchments of the main tributaries of Lake Brunner, including Inchbonnie, to predict the water quality in Lake Brunner if the nutrient benchmarks were achieved.

4.2.1 The CLUES model

CLUES is a GIS based model that predicts and quantifies the effects of land use change on water quality. Development of the CLUES model began in 2004 fuelled by the need to model the effects of potential land use situations on water quality at a large scale. The project was led by Ministry of Agriculture and Fisheries (MAF) and Ministry for the Environment (MFE). The National Institute of Water and Atmospherics (NIWA) and five other contractors, Lincoln Ventures, Harris Consulting, AgResearch, HortResearch and Landcare Research, were also involved with developing it. The modelling framework for CLUES is illustrated in Figure 4.2. This describes the data layers contained within CLUES; the models which constitute CLUES, the users inputs and the generated results. This framework will be described in detail in the following sections.

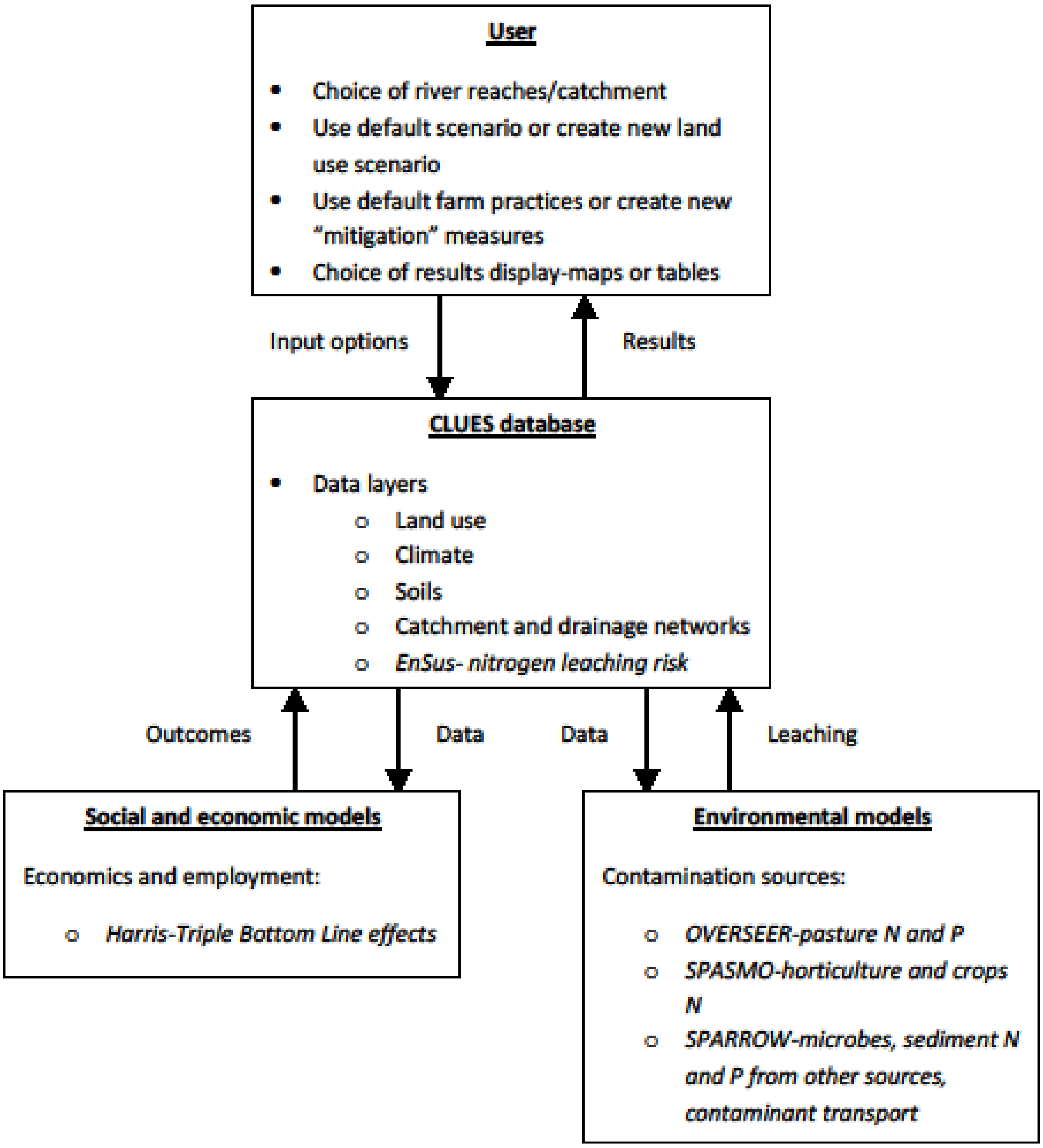

Figure 4.2: CLUES modelling framework. Adapted from "The CLUES project: Tutorial manual for CLUES 3.1 by Semadeni-Davies et al., 2011, NIWA Client Report No. HAM2011-003.

Components of the CLUES model

CLUES incorporates a series of modules into one tool. These modules were created by manipulating or simplifying existing models to work within a GIS platform (Elliott et al., 2011; Semadeni-Davies et al., 2011; Woods et al., 2006). The five modules included within CLUES are: Soil Plant

Atmosphere System Model (SPASMO) created by HortResearch to ascertain nitrogen losses for horticulture scenarios including pasture. OVERSEER, created by AgResearch, which calculates nutrient losses for pastoral systems including dairying, deer, sheep and beef; Spatially Referenced Regression on Watershed Attributes (SPARROW) developed by the United States Geological Survey (USGS) and modified to fit New Zealand conditions (SPARROW calculates expected average annual total phosphorus, total nitrogen, sediment and *E-coli* stream loads) and Environmental Sustainability (EnSus) developed by Landcare Research which presents a map of nitrogen leaching risk (Lilburne et al., 2011; Semadeni-Davies et al., 2011). The fifth model is called Triple Bottom Line (TBL). It was developed by Harris Consulting and determines the economic outcomes of land use change. The economic modelling has been deemed to be outside the scope of this research.

There is limited quantified data in New Zealand to accurately describe the relationship between surface water and groundwater (Woods et al., 2004). Groundwater processes cannot be easily observed and groundwater flows do not necessarily follow the same pattern as the surface topography. Several groundwater systems may also be layered on top of each other. As a result it is difficult to model groundwater and a groundwater model is not currently included in CLUES (Woods et al., 2004). The existing CLUES stage reports describe how SPARROW could be employed to create a basic groundwater model by copying the surface water stream network (Woods et al., 2006; Woods et al., 2004). This is yet to be implemented in the latest CLUES model which assumes the groundwater will appear in the same surface water catchment (Lilburne et al., 2011). This limitation within CLUES will be examined further in Chapter 6.

The CLUES user interface is accessed through ArcGIS. Users are presented with the CLUES toolbar illustrated in Figure 4.3 and geo-referenced data at a regional scale illustrated in Figure 4.4 (Semadeni-Davies et al., 2011). CLUES takes advantage of the ability of GIS software to input, store, manipulate and display large amounts of geo-referenced data (Elliott et al., 2011; Semadeni-Davies et al., 2011). The smallest spatial unit in CLUES is the sub-catchment associated with individual river reaches from the River Environment Classification (REC) data. These sub-catchments are on average 0.5km² and are the smallest area that CLUES can make enquiries about. It cannot make farm scale enquiries. Each sub-catchment has geo-spatial data relating to it presented as a series of GIS map layers (Semadeni-Davies et al., 2011). These layers are superimposed so the geographic location of any particular sub-catchment has a series of relevant data associated with it. This data can be retrieved and analysed either spatially or according to attributes (Clarke, 2003; DeMers, 1997).

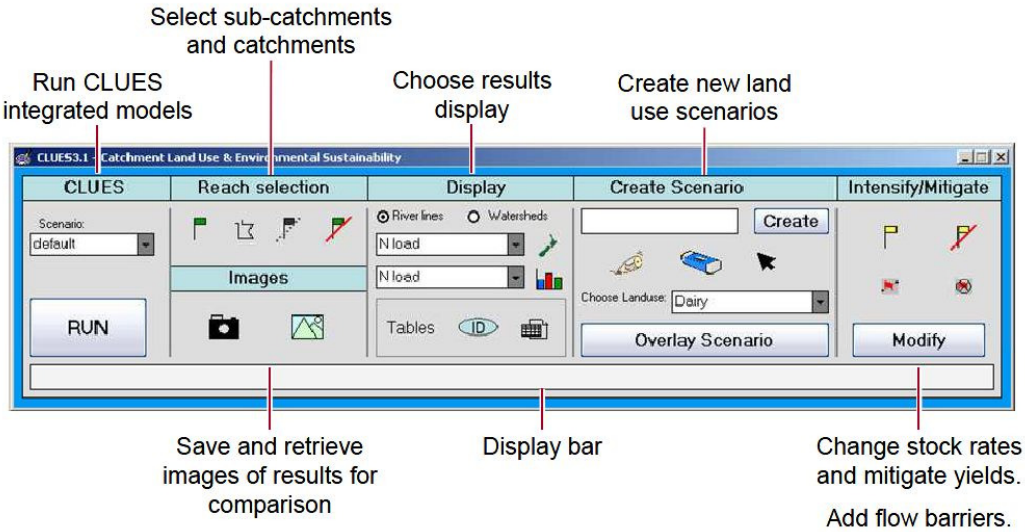

Figure 4.3. CLUES 3.0 toolbar from "The CLUES project: Tutorial manual for CLUES 3.1 by Semadeni-Davies et al., 2011, NIWA Client Report No. HAM2011-003.

The map layers which come as part of CLUES contain all the georeferenced data required to run the model. This includes land use, area, climate and hydrological data and soil properties (Semadeni-Davies et al., 2011). 'Hydroedge' and 'streams' are two important layers. They contain information about each river reach such as; River Environment Classification (REC) which is a national identification number, reach length, channel slope and position in the stream network. Catchment attributes are stored within the 'catchment' layer. This layer contains data relating to boundaries and areas of sub catchments, soil types, land use and estimated surface runoff (Semadeni-Davies et al., 2011). There are a lot of informative layers such as 'nzcoast', which maps the coast and 'AllLakes' which map New Zealand lakes. The world imagery provides satellite images as well as the location of State and Main Highways. These layers are illustrated in Figure 4.4.

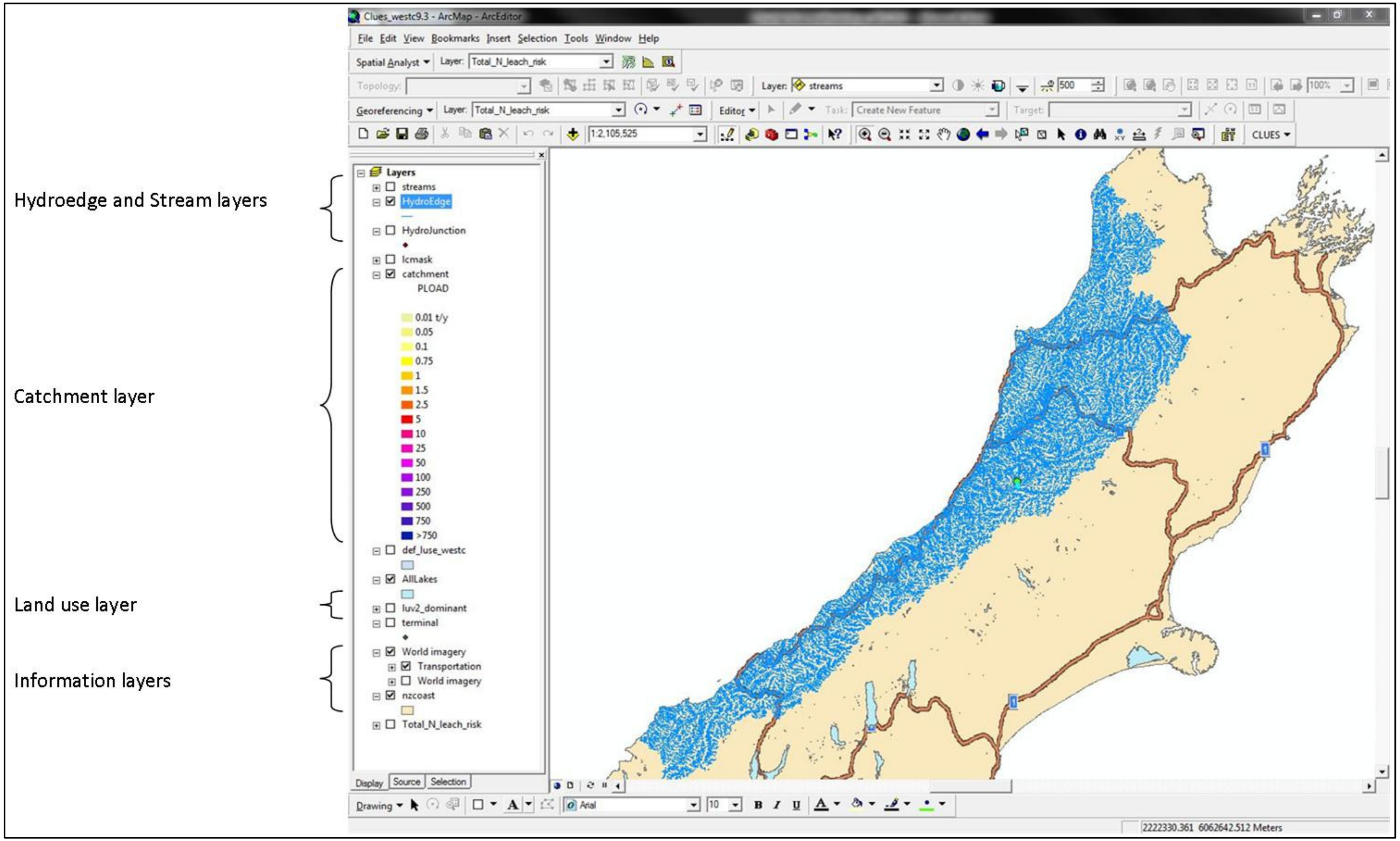

Figure 4.4. Screenshot from CLUES running in ArcMap showing the extent of the regional data layer for the West Coast as well as the layers included in CLUES in the Table of Contents to the left.

Running the CLUES model

The CLUES user can run different scenarios through the model. CLUES comes with one default scenario. The user can create new scenarios. These new scenarios are copies of the default scenario which the user then modifies. Land use in the catchments can be modified by importing a new land use layer or manually altering the existing layer. There are also mitigation methods available which include changing stocking rates, TN, TP, *E. coli* or sediment loss. These can also be altered manually or through importation of a new layer.

After the user has chosen a scenario, or created and modified a scenario, the river catchment, or series of river catchments the user is interested in are selected using tools from the CLUES toolbar. The CLUES model is then "run" for the chosen scenario. The results of the scenario are returned in several formats. The water quality results are recorded in the attribute table of the catchment layer. The CLUES toolbar provides the options to display the results as either graduated colours on maps, a table with the results for each individual river reach or a table with the results of a specific river reach.

CLUES 3.1 currently calculates the following results:

- Total N and P loads (t/yr)
- Sediment load (kt/yr)
- *E-coli* loads (10^{15} organisms/yr)
- Total N and P concentrations (mg/m^3)(median)
- Total N and P yields (kg/ha/yr) (Generated and Cumulative)
- Generated Sediment yields (t/ha/yr)
- Total Nitrogen loss risk (scale from very high to very low)

Calculation of nitrogen and phosphorus losses

Nitrogen and Phosphorus are the key focus for this research. CLUES 3.1 simulates N and P losses from dairy farms using a simplified version of OVERSEER. OVERSEER is described as a decision system model (MAF FertResearch and AgResearch, 2010; Wheeler et al., 2003). Its primary use is to help farmers, consultants and policy makers develop nutrient budgets. OVERSEER has the ability to calculate budgets for sheep, deer, beef and dairy farms as well as arable crop farms. It measures inputs and outputs of nutrient flows for a farm, or farm block (paddock). The resulting nutrient budgets include fertiliser nutrient and lime needs, N leaching and run-off, P run-off and risk and green house gas emissions (MAF FertResearch and AgResearch, 2010; Wheeler et al., 2003). The simplified version of OVERSEER used in CLUES is a dll (dynamically linked library) which is effectively a reference chart calibrated from OVERSEER results (Lilburne et al., 2011). When a scenario is run, CLUES inputs values such as stocking rate, land use, rainfall and topography from the scenario into the OVERSEER table and returns the N leaching and P loss values that correspond to them. An additional P loss dairy term is included in CLUES 3.1 for dairy farm land use. It takes into consideration losses such as farm dairy effluent and faecal deposition. The additional dairy term increases the P loss from OVERSEER (Monaghan et al., 2010). The values from OVERSEER are converted to the N and P yields and loads.

Calculations of nitrogen and phosphorus concentrations

Nitrogen and Phosphorus concentrations predicted by CLUES are median concentrations (C_m). They are time weighted and independent of flow. This value is predicted by CLUES for individual sub catchments using the ratio in Equation 1 from Semadeni-Davies (2011) between median concentration and flow-weighted concentration (C_{fw}). This ratio has been derived from the relationship between C_m and C_{fw} for rivers from the National River Water Quality Network (NRWQN). The NRWQN is a long term program that monitors 35 major rivers throughout New Zealand (NIWA, 2012).

Equation 1. Ratio between median concentration and flow-weighted concentration

$$R = \frac{C_m}{C_{fw}}$$

Flow-weighted concentration is calculated from the average annual load (L, t/yr) and the mean annual flow (Q, m^3/s) from CLUES using Equation 2 from Semadeni-Davies (2011).

Equation 2. Relationship of flow weighted concentration with mean annual load and mean annual flow from the hydroedge layer within CLUES

$$C_{fw} = \frac{10^9 L}{365.25 \times 86400 Q}$$

The results of this research will report the flow-weighted concentration calculated using Equation 2 not the median concentration predicted by CLUES. This is because the water quality data which is used for comparison is given as a flow-weighted concentration.

Calculation of mitigations

CLUES provides users with the ability to increase or decrease the stocking rate, TP, TN, *E. coli* and sediment yields. The modification table from CLUES is shown in Figure 4.5. Modifications cannot be made by entering the desired yield in kg/ha/yr into CLUES. Instead modifications are made by changing the yields from a particular land use by a defined percentage of the default yield.

The default or unchanged TN, TP, *E. coli* and sediment yields are represented as 100, or 100% of the default yield illustrated in Figure 4.5. The value inserted into the table is the percentage that will remain after modification. A reduction in yield is represented as a lower percentage: this means a 20% decrease results in a new yield which is 80% of the default yield. An increase is represented by a higher percentage ie a 20% increase results in a new yield which is 120% of the default yield.

Modifications of stocking rates and yields can be achieved by manually changing the yield or by importing a table with the modifications into CLUES. An advantage of importing a table is that yields can be effectively modified to a specific yield in kg/ha/yr. Yields for each sub-catchment can be extracted from the default scenario's attribute table. The percentage change required to meet the specified yield can be calculated from these default yields and tabulated. This table can then be imported into CLUES. This method of modelling the effect of catchment benchmarks on water quality in CLUES has not been used in any published studies before.

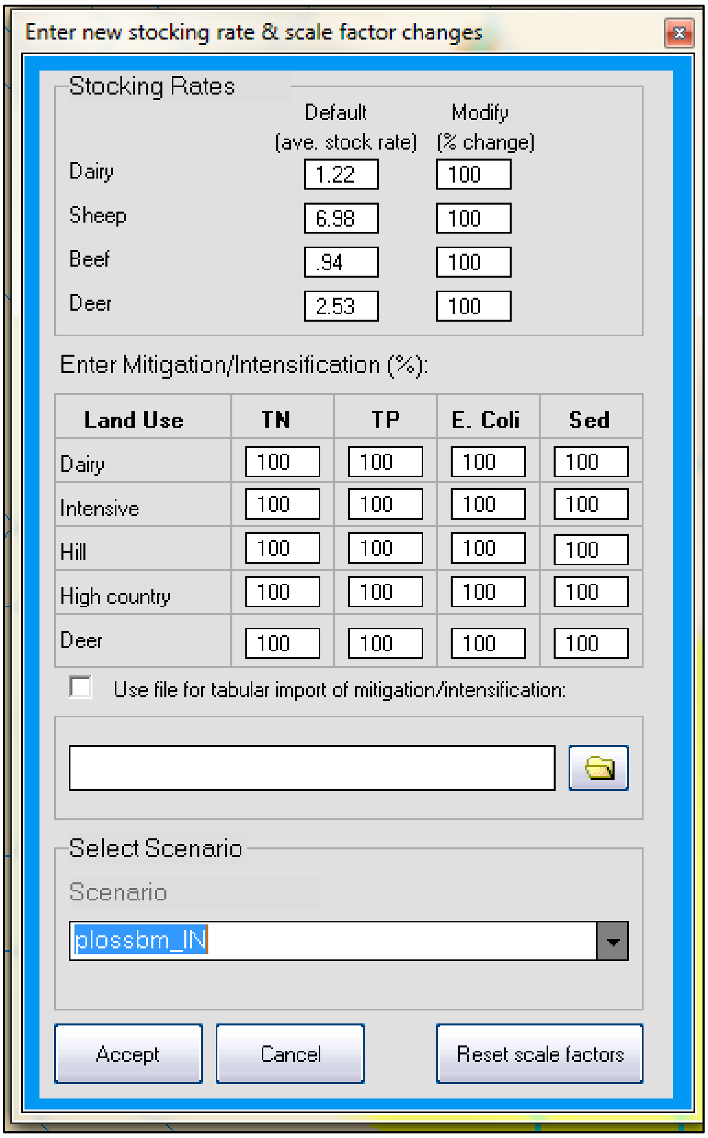

Figure 4.5. Modification table modified from a screenshot from CLUES 3.0. The Modify (% change) columns all read 100 as they have not yet been changed from the default.

4.2.2 Scenario One: current water quality

The first scenario run through CLUES was a prediction of the current water quality in each of the two catchments. The stocking rate and land use were updated in Scenario One using built in CLUES functions to improve the accuracy of the model. The default stocking rates provided in CLUES differed from the most recent available stocking rates. For Waikakahi the default rate was 2.67 cows/ha and was adjusted to 2.8 cows/ha (Ministry for the Environment, 2009). In Inchbonnie the default was 1.22 cows/ha and was changed to 1.77 cows/ha (Rutherford et al., 2008).

The default land use layer within CLUES references a combination of geo-databases; Land Cover Database (LCBD2) by Ministry for the Environment, 2001 AgriBase by AsureQuality, and Land Environments of New Zealand (LENZ) by Landcare Research (Lilburne et al., 2011). This data is now up to ten years old and the land use in the catchments had changed. The 2010 land use map for the Inchbonnie catchment (provided by Alison Rutherford, environmental research specialist at AgResearch) showed the catchment was 100% dairy as illustrated in Figure 4.6. The land use layer for the current Inchbonnie scenario was changed accordingly.

The 2010 land use map for the Waikakahi catchment provided from AgResearch illustrated in Figure 4.7 only includes the current land use in the BPDC area. The hydrological definition of the Waikakahi catchment includes both the BPDC area (light blue in Figure 4.8) and the adjoining hillside areas (lime green in Figure 4.8). The entire hydrological area was modelled in CLUES because the water quality monitoring site includes this hill area. The 2010 land use map was imported into CLUES, georeferenced and digitised to assign current land uses to the appropriate specific geographic area. The land use in the current Waikakahi scenario was changed to this new layer which includes the 2010 land use map and original hill area land use as in Figure 4.8.

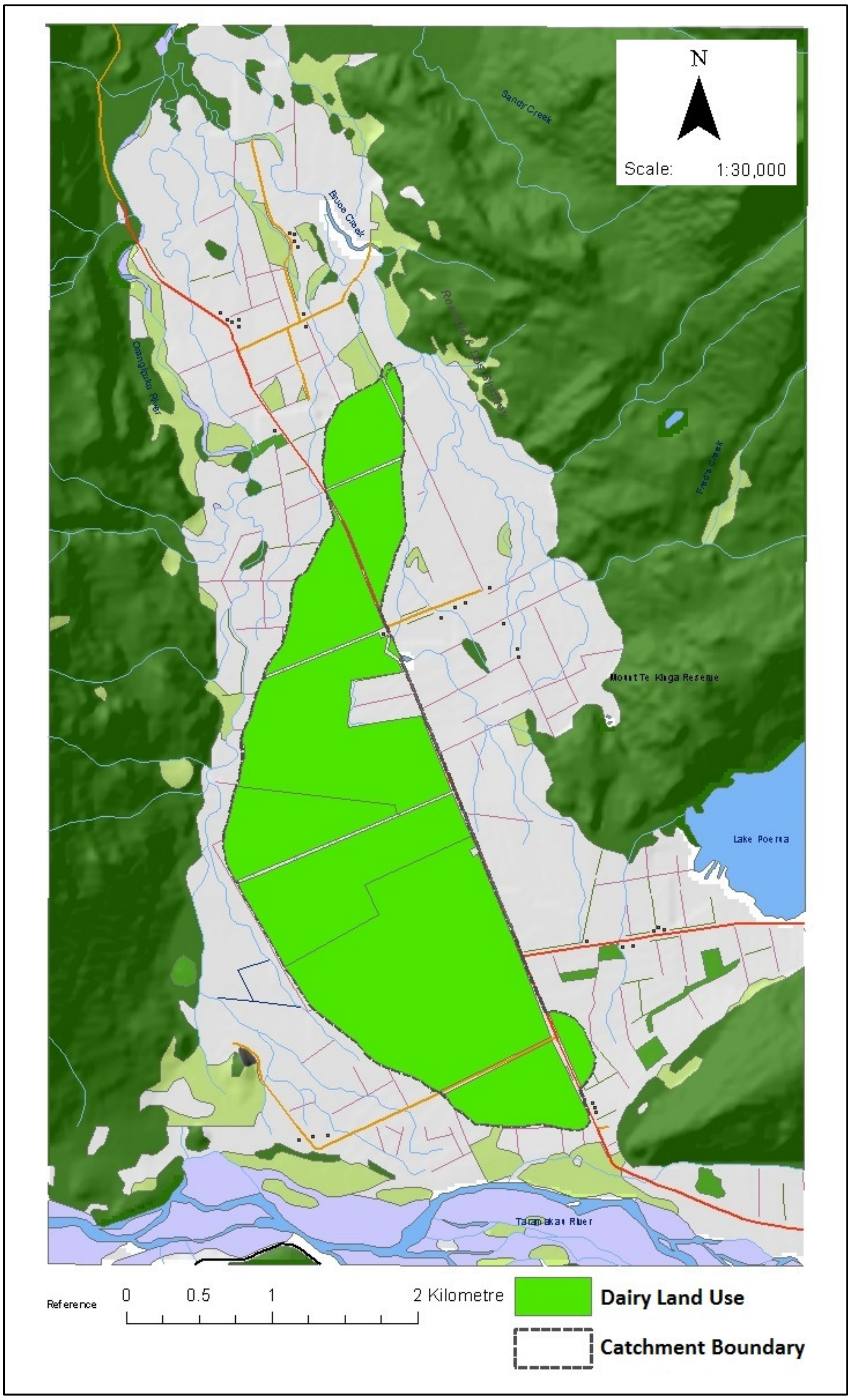

Figure 4.6. Map of land use in the Inchbonnie catchment in 2010. Provided by Alison Rutherford, environmental research specialist at AgResearch.

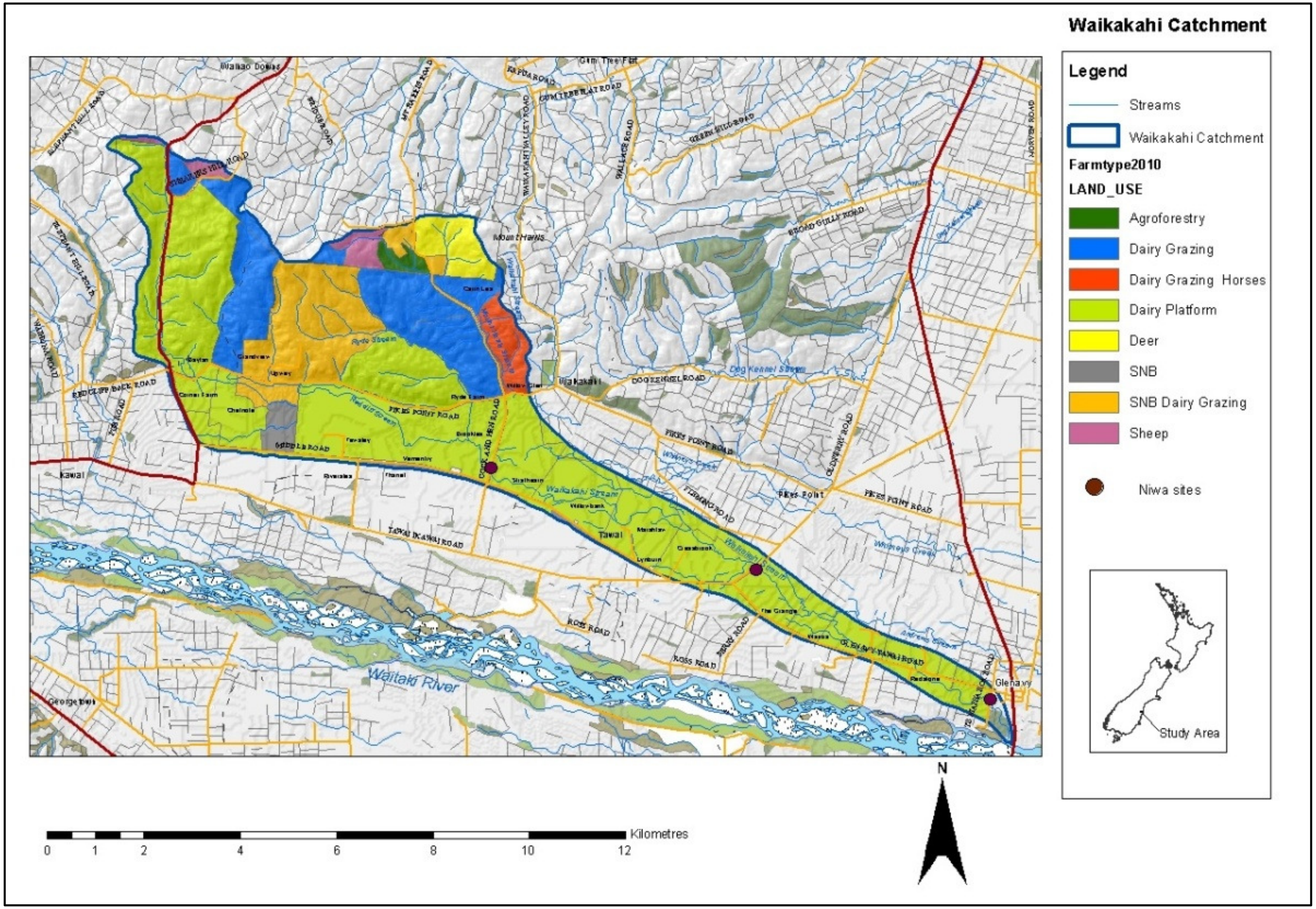

Figure 4.7. Map of 2010 land use layer for the BPDC Waikakahi catchment. Provided by Alison Rutherford, environmental research specialist at AgResearch

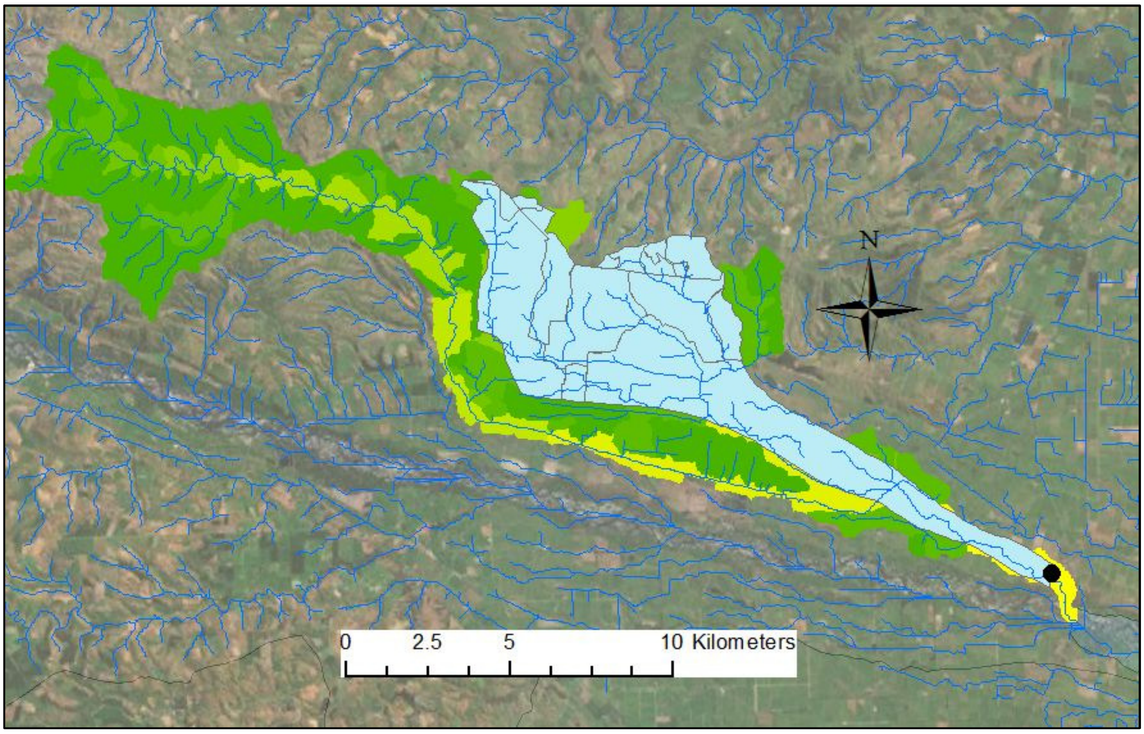

Figure 4.8. Waikakahi catchment showing both the BPDC definition area in light blue and the hydrological definition area in greens

Measured water quality data for comparison

The Scenario One results were compared to measured water quality data from Wilcock et al. (2007) at the outlets of the catchments. Data was from 2001 to 2006 for Waikakahi and 2004 to 2006 for Inchbonnie. Wilcock et al. (2007) calculated nutrient loads using the product of flow weighted mean concentration and true mean flow, determined from daily flow data. This well recognised method is described in Fergusson (1987) *Accuracy and Precision of Methods for Estimating River Loads*.

Water quality data was provided to the researcher for the period 2006 to 2010 courtesy of Dr. Bob Wilcock Principal Scientist at NIWA. However it did not include daily flow measurements, only monthly gauged flows. As a result the method used by Wilcock et al. (2007) could not be replicated by the researcher on the 2006 to 2010 data. The Wilcock et al. (2007) data was considered more robust and as a result is used to compare to Scenario One predictions.

4.2.3 Scenario Two: water quality predictions with benchmarks

The second scenario run in CLUES predicted water quality in the two catchments if the proposed benchmarks were introduced and achieved. The DairyNZ benchmarking project sets both N and P loss benchmarks as well as N use efficiency benchmarks. Mitigations in N use efficiency cannot be modelled in CLUES to predict potential changes in water quality. This is because the correlation between N use efficiency and N loss is not strong. There are also no N use efficiency benchmarks currently proposed for either catchment.

A provisional P loss benchmark, that is a reduction from each farm of 0.65 kgP/ha/yr, has been proposed for the Inchbonnie catchment. It is not a fixed benchmark, but rather a reduction of current yield that is considered to be achievable by all farms in the catchment. This benchmark has been derived from farm scale modelling of potential P loss mitigation methods in the Inchbonnie catchment by AgResearch. All five farms in the Inchbonnie catchment were individually assessed. Farmers chose three mitigations from a list of seven which were modelled for their farm system to determine effectiveness in reducing P losses, and also their cost-effectiveness. The mitigations were modelled separately and in combination (Laurenson et al., 2012). The proposed benchmark used in this research is derived from the average loss from the combined mitigation measures on all five Inchbonnie farms (S. Hayward, personal communication February 1, 2012). No N loss benchmarks has been proposed for the Inchbonnie Catchment.

A provisional N loss benchmark of 24 kgN/ha/yr was proposed in May 2011 for the Waikakahi catchment. This benchmark was based on the 25th percentile value for N leaching from Canterbury farms (DairyNZ, 2011b). It will be used because an achievable N loss benchmark has not yet been derived from farm scale modelling of potential mitigation methods. The 24 kgN/ha/yr benchmark is based on a reasonable mitigation target for the catchment and will provide some understanding of what can be achieved. No P loss benchmark has been proposed for the Waikakahi Catchment. It is important to note that the benchmarks are provisional at this time. The farmers in the catchments and the wider farming community have not had the opportunity to collectively discuss whether they are appropriate for their catchments.

The proposed N and P loss benchmarks were added to Scenario Two using the second method described in Section 4.2.1-The CLUES model. In order to introduce the P loss benchmark to the Inchbonnie catchment the Total Phosphorus (TP) percentage change required for the TP yields for each sub-catchment from the current scenario to be reduced by 0.65 kgP/ha/yr were calculated in Excel. This spreadsheet was imported into CLUES and used as the modification table. Introducing the N loss benchmark to the Waikakahi catchment was slightly more complex. Only twelve of the 260 sub catchments that make up the Waikakahi catchment had generated Total Nitrogen (TN) yields greater than 24 kgN/ha/yr in the current scenario. These sub-catchments were in the heart of the dairying area in the catchment as illustrated in Figure 4.9. This may explain why they were the only sub-catchments with such high TN yields. The percentage change required for the TN yields from those twelve sub-catchment to equal the 24 kgN/ha/yr benchmark was calculated in Excel. The rest were left as 100 and this external file was imported into CLUES.

The absolute values predicted by CLUES and other models of its sort are not considered to be completely reliable. This is evident in the results of the Scenario One predictions in Chapter 5. However, the relative change between the scenarios is believed to provide a good indication of what could be expected (Elliott et al., 2011; Lilburne et al., 2011; Monaghan et al., 2010). In Chapter 5 the difference between Scenario One and Scenario Two predictions (relative change) will be used as an indication of the improvement that can be expected to occur to the measured water quality values following the implementation of benchmarks in the catchments.

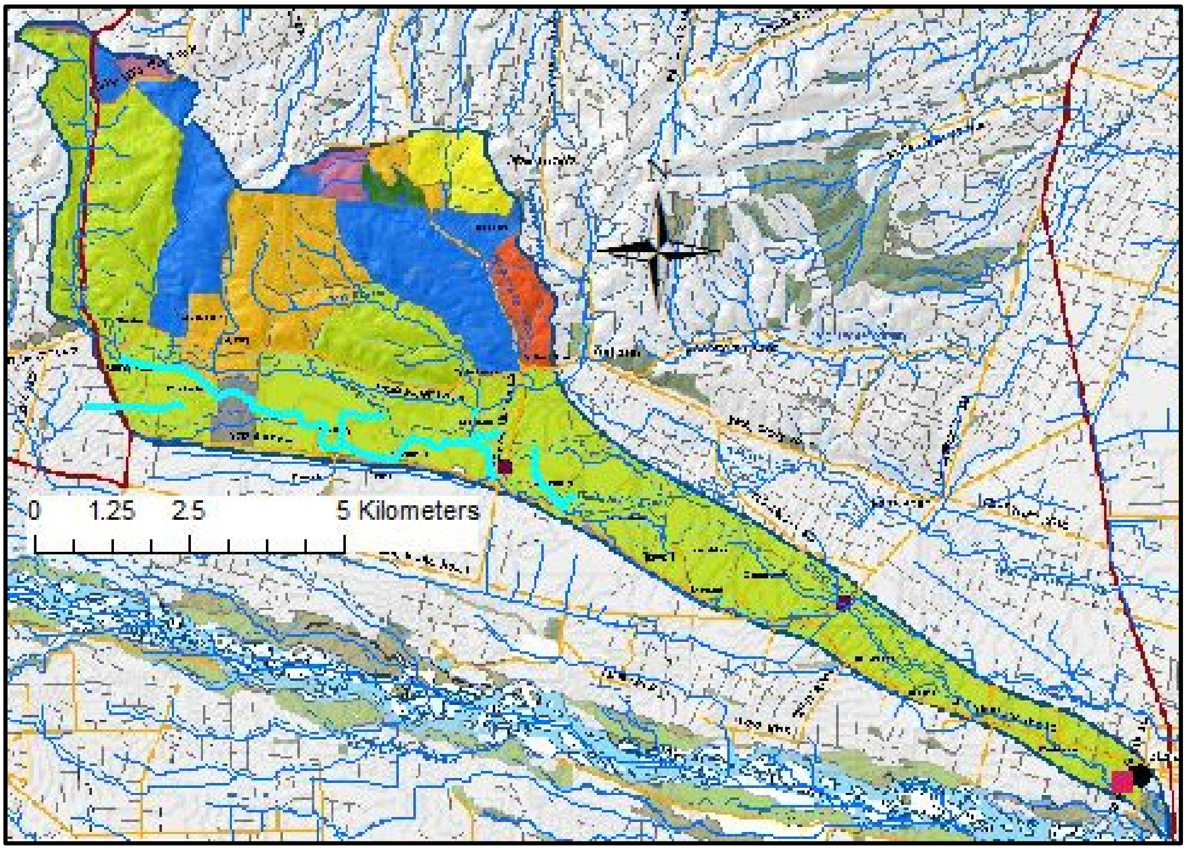

Figure 4.9. The BPDC area of the Waikakahi catchment showing the location of the twelve sub catchments that have generated yields over 24kgN/ha/yr in highlighter blue. Note they all occur within the dairying land use area (shown in green)

Water quality values for comparison with predictions

The predicted water quality from Scenario Two in each catchment will be compared with two values. This will help to determine whether the benchmarks effectively manage nutrient loss and result in an adequate improvement in water quality in the catchments. Both of the catchments will be compared to the New Zealand TP or TN concentration trigger values for the protection of aquatic ecosystems from the Australian and New Zealand Environment Conservation Council (ANZECC) guidelines (2000). The Waikakahi TN prediction from Scenario Two will also be compared to a nitrate toxicity value in streams developed by Environment Canterbury. These standards are described in this section. There are no equivalent guidelines determined for TP in streams by West Coast Regional Council which could be used for the Inchbonnie TP Scenario Two predictions. They will instead be compared to a value that is applicable for the management of Lake Brunner's water quality. This is described in the following section.

The ANZECC (2000) trigger values calculate the level of physical and chemical stressors (e.g., nutrient concentrations) in a waterway which may cause ecological or biological effects. A breach of the trigger values is an indication that further investigation of water quality issues and risks is needed. It does not necessarily mean that negative ecological and biological effects will transpire. In catchments where water quality does not breach the trigger values, there can be reasonable confidence that it is supporting ecological values (Ballantine et al., 2010).The ANZECC (2000) trigger values are commonly used in New Zealand in the absence of locally derived guidelines (Ministry for the Environment, 2009; Monaghan et al., 2009b). The Waikakahi and Inchbonnie Catchments can both be classified as slightly disturbed ecosystems (ANZECC, 2000; Ministry for the Environment, 2009). The trigger values for TN and TP for protection of slightly disturbed ecosystems in lowland rivers are: TN = 0.614mg/L and TP=0.033 mg/L.

While the ANZECC water quality guidelines provide default trigger values, they also maintain that where possible locally derived water quality limits based on acceptable levels of risk should be developed and used (ANZECC, 2000). For this reason predicted water quality in the catchments was also compared to standards developed by the appropriate regional councils. Neither regional council has set their own TP or TN water quality targets for lowland streams. Environment Canterbury has set water quality standards for soluble nutrient concentrations in its Natural Resources Regional Plan which will be compared against predicted water quality in the Waikakahi Catchment (Environment Canterbury, 2010a).

Environment Canterbury sought a review of the current nitrate toxicity guidelines set in ANZECC (2000) and their relevance to Canterbury rivers and streams. The resultant revised nitrate toxicity guidelines developed by Hickey and Martin (2009) will also be used for comparison with water quality prediction from Scenario Two for the Waikakahi catchment. Nitrate, which is soluble and bioavailable (Figure 2.2) is the form of N which is of most concern in the Waikakahi catchment. If conditions are favourable and other nutrients not limiting, nitrate can stimulate an increase in plant growth which smothers the stream habitat and reduces drainage. Nitrate can also be highly toxic to aquatic life (Hickey & Martin, 2009). Hickey and Martin (2009) recommend a revised nitrate-nitrogen concentration limit of 1.7 mg/L for a 95 % level of protection, which is deemed a suitable level of protection for slightly to moderately disturbed systems (ANZECC, 2000).

CLUES only predicts total nitrogen (TN) which includes all forms of nitrogen. It does not predict loads or concentrations of dissolved nutrient fractions such as nitrate. In order to compare TN loads and concentrations predicted by CLUES to nitrate (NO_3) toxicity guidelines, the water quality data for the Waikakahi Stream was examined to determine the relationship between nitrate-nitrite nitrogen (NNN) to total nitrogen (TN) concentrations following the approach taken by Kelly & Norton (2010). This determined the regression y= 0.9485x–0.2946, R^2=0.9195. This good regression relationship is illustrated in Figure 4.10.

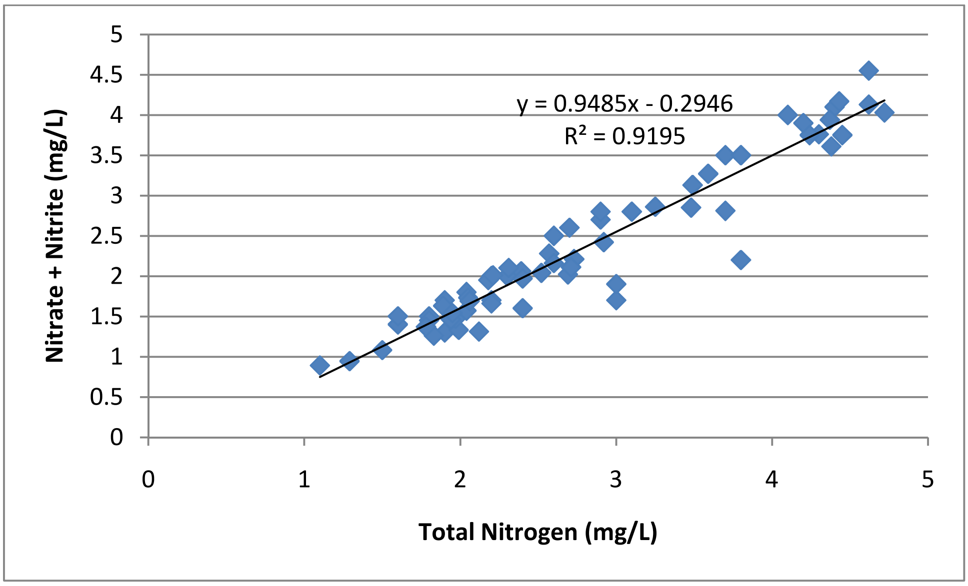

Figure 4.10. Regression analysis of the linear relationship between TN and NNN using combined data from Environment Canterbury and NIWA at Te Maiharoa road (same location where the water quality data used for comparison is measured).

Nitrate-nitrite nitrogen (NNN) is the common laboratory measurement of nitrogen in freshwaters. It is the measurement of the combined concentrations of nitrate (NO_3) and nitrite (NO_2) nitrogen. NO_2 is unstable in the presence of oxygen and is rapidly oxidised to NO_3; this is illustrated in Figure 2.2. It is generally assumed that NO_2 does not exist in measureable quantities in Canterbury rivers because they are usually well-aerated and oxidised. Therefore, measurements of NNN can be assumed to be a measurement of NO_3 concentrations (Stevenson et al., 2010). A guideline TN concentration for the Waikakahi Catchment can then be calculated using Equation 3 where the nitrate value is substituted for NNN. Achieving this TN value, 2.10 mg/L, should prevent nitrate toxicity at a level which would threaten sensitive species.

Equation 3. Calculation of TN concentration using the regression relationship between NNN and TN

$$TN = \frac{NNN + 0.2946}{0.9485} = \frac{(1.7) + 0.2946}{0.9485} = 2.10\ mg/L$$

4.2.4 Methodology for modelling Lake Brunner

Inchbonnie is a small catchment within the larger Orangipuku catchment. The Orangipuku is in turn, one of the three major tributaries within the Lake Brunner catchment. The water quality of Lake Brunner is a driver behind the inclusion of the Inchbonnie catchment in the BPDC project. The concept of a P loss benchmark for the Inchbonnie was developed with the expectation that it could eventually be introduced to dairy farms within the entire Lake Brunner catchment. This would reduce the P load entering the lake from its tributaries, and help maintain the desired TP levels in the lake. The three main tributary catchments of Lake Brunner are Orangipuku, Hohonu and Crooked. The river networks which make up these catchments are illustrated in light blue in Figure 4.11. As indicated in the preceding section, there is no TP value set by West Coast Regional Council for streams which could be compared to water quality predictions in the Inchbonnie catchment. There is however a proposed Trophic Level Index (TLI) value to maintain water quality in Lake Brunner. The TP portion of the TLI for Lake Brunner can be determined. This TP value is compared to the Scenario Two predictions to provide a regional relevant water quality comparison in the Lake Brunner catchment. This will also provide an appropriate measure of the success of the benchmark in the Inchbonnie catchment.

The same two scenarios that were run on the Inchbonnie catchment were also run on the Orangipuku, Hohonu and Crooked catchments. Scenario One predicted the current water quality in the catchments using default CLUES values. TP yields from a report prepared for the West Coast Regional Council were compared to TP yields predicted in Scenario One (Rutherford et al., 2008). Measured TP concentrations were not given in Rutherford et al. (2008). The mean TP concentration of all the inflows to Lake Brunner is given in another report prepared for the West Coast Regional Council as 12.5-13.5 mg/m³ (Verburg, 2009). The three catchments modelled make up 78% of the inflow to the lake and include the majority of dairy farms in the catchment. As a result the average TP concentration inflow from these three catchments combined should be similar to the average total TP concentration inflow to the lake (Verburg, 2009).

The predicted average TP concentration in Lake Brunner ($[P]_{lake}$, mg/m³) for Scenario One was calculated from the average predicted flow weighted TP concentration of the three catchments from Scenario One CLUES predictions ($[P]_{inflow}$, mg/m³) and the residence time of Lake Brunner (T_w, yr) using Equation 4 from Verburg (2009).

Equation 4. Relationship between P concentration of P in Lake Brunner and average P concentration in the inflows

$$[P]_{lake} = \frac{[P]_{inflow}}{(1 + \sqrt{T_w})}$$

In Scenario Two the benchmark reducing P yield on every farm by 0.65 kg/P/ha/yr was introduced to the three catchments. The predicted TP concentration of the lake following the benchmark introduction was also calculated using Equation 4. This concentration will be compared to the proposed TP concentration aim for Lake Brunner of 7 mg/m³. This aim is derived from the proposed TLI target for Lake Brunner by the West Coast Regional Council and will maintain current water quality and clarity levels (S. Hayward, personal communication, January 13, 2012).

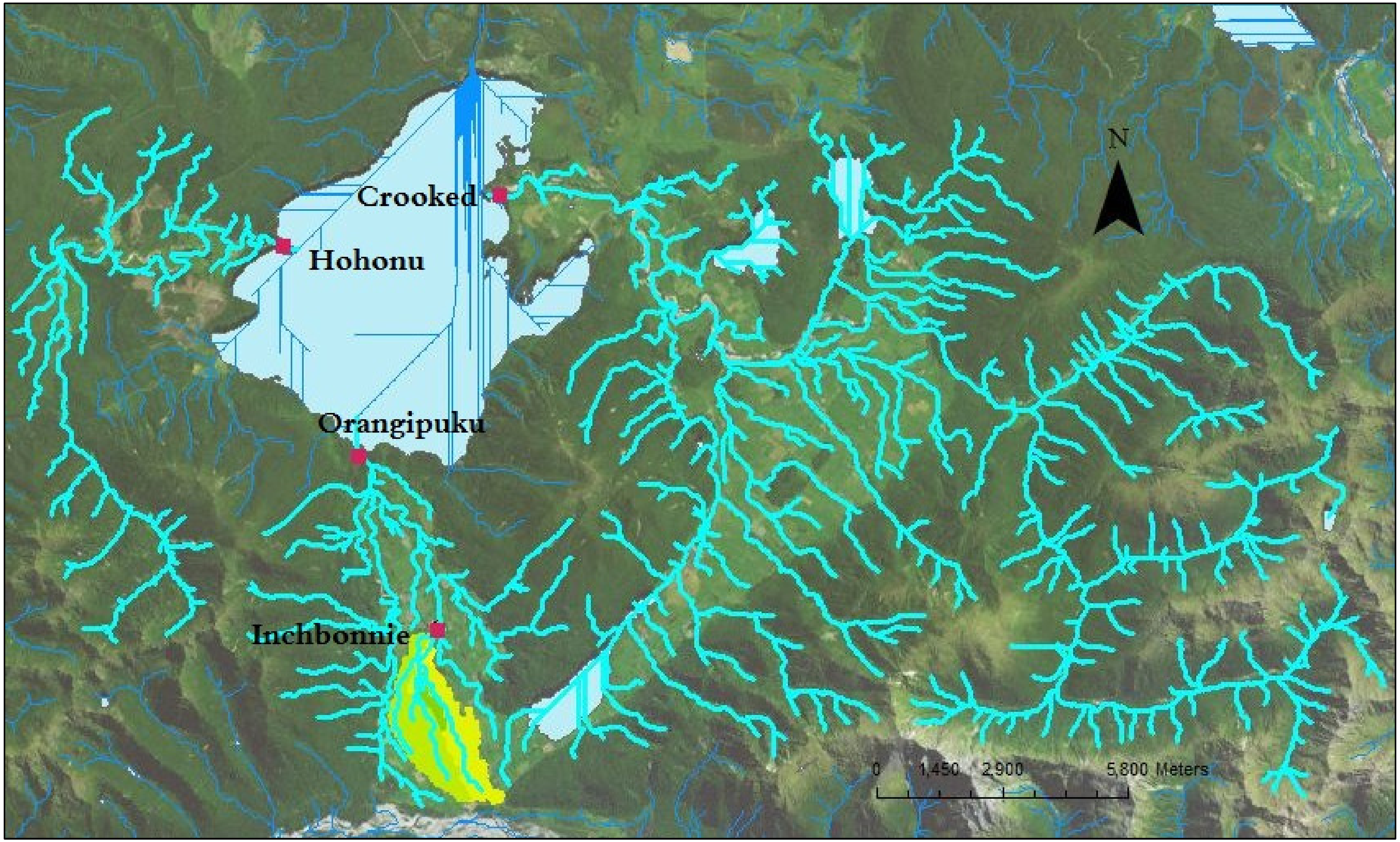

Figure 4.11. Lake Brunner showing the location of the three catchments which are the main tributaries to the lake; Crooked, Hohonu and Orangipuku. The Inchbonnie BPDC is shown in its location within the larger Orangipuku catchment.

4.2.5 Display of results

The modelling output is displayed in two styles in Chapter 5. The predicted water quality loads are displayed as graduated colours on maps with an associated legend. Scenario One will be displayed alongside Scenario Two and compared to give a visual analysis of the potential changes. Specific N and P loadings for Scenarios One and Two are also extracted from the attribute tables within ArcMap and displayed in tables.

4.2.6 Errors in modelling methodology

There are potential sources of error that arise from the data and calculations used within the CLUES model. The CLUES model can be referred to as a black box model. This means the inputs and outputs are known, however the equations or processes within the model are unknown to the user (Wainwright & Mulligan, 2004). It is therefore very difficult to quantify or minimise these errors. As shown in Section 4.2.2-Scenario One: current water quality, the input data has been updated to improve accuracy of predictions. The limitations of the CLUES model are discussed in further detail in Chapter 6.

The process of geo-referencing occurred when the 2010 land use map for Waikakahi was imported into CLUES. It has the potential to introduce spatial errors into the selection of river reaches in the Waikakahi catchment. Ground control points (GCP) are points on the ground surface with a known location that occur both in the original map and in the map being georeferenced. Ideally they should be natural features as they are unlikely to change location. There are no constant natural features on both maps as one was an aerial photograph and the other a computer generated sketch. Bends on roads were used as GCP instead of natural features. The small number of GCP reduces the accuracy of the georeferencing; more GCP provides increased triangulation which ensures the map is correctly located in space (DeMers, 1997). RMS (root mean square) is the difference between the final location of the GCP in comparison to the actual location that was specified by the user when selecting the point. It provides a measure of residual error as opposed to the accuracy of the georeferencing. In general having a RMS smaller than the pixel size of the photographs is satisfactory (ESRI, 2009). Georeferencing the land use map resulted in a relatively large RMS of 7.26. This occurred because it was difficult to select well distributed GCP that were in both the computer generated sketch and the orthophoto. It is still smaller than the pixel size of the Waikakahi land use maps which were 14m.

The measured NIWA water quality data which is used for comparison with the current water quality in the catchments is an area with potential to introduce errors. It is possible there will be some instrumental or human errors that occurred during the collection of this data. However, as the source of the data is NIWA, a highly regarded research institute in New Zealand, these errors should not be significant. Flow measurements are generally accurate to within +/- 3%. TP and TN detection levels from the NIWA water quality lab are 10 mg/m^3 for TN and 1 mg/m^3 for TP. This makes uncertainty in the measurements small. The levels of TP and TN detected in the Waikakahi and Inchbonnie Catchments are in the order of 100 times greater than these (B. Wilcock, personal communication, 18 November, 2011).

Chapter 5 Results

The purpose of this chapter is to display the findings from the qualitative farmer interviews and the quantitative water quality modelling. The results of interviews the will be presented first followed by the results of the water quality modelling from CLUES.

5.1 Results of farmer interviews

This aims to understand how dairy farmers in the Best Practice Dairy Catchments perceived the nutrient benchmarks. The main source of data used is interviews with dairy farmers in the Waikakahi and Inchbonnie catchments. Observations of dairy farmer meetings attended by the researcher are used as secondary data sources. The section begins by describing the characteristics of the farmers interviewed. It is then divided into two sections:

- Understanding and opinions of current nutrient management
- Understanding and opinions of nutrient benchmarks

As described in Chapter 4 each interview was coded to tease out the main manifest and latent messages in the responses. Seven main themes emerged from this coding: effluent and fertiliser application; increase productivity, profits and efficiency; environmental concern; current guidelines and practices; regulation/resource consent; peer pressure/community views; understanding, education and behaviour change. The results of the interviews will be described in relation to the quantitative results and these key themes. Quotes from the interviews are employed to support observations of illustrate themes. The quotes are recorded exactly how the farmers spoke which was often in short incomplete sentences.

5.1.1 Characteristics of the farmers interviewed

A simple system was devised to link the respondents to their catchments. Each respondent was assigned a number (001-008) and the prefix of WK for Waikakahi or IN for Inchbonnie depending on the catchment they came from. Farmer characteristics are not described individually as that may compromise the anonymity of the respondents. Basic descriptive statistics are employed in Table 5.1 to provide an understanding of the farmers interviewed.

Table 5.1. Basic demographic statistics from farmer interviews

	Farm Size (ha)			Years the farmer has farmed in the Region			Years involved in Dairy Farming		
	Average	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum
WK	376	161	620	10	4	22	22	7	55
IN	206	170	240	17	1/2	32	24	17	37

The average farm size is larger than the average reported in the (2009) Ministry for the Environment report *Water quality in selected dairy farming catchments*. This is likely just a difference in the sample and population average. In the Inchbonnie catchment three out of the five dairy farmers completed the survey. Two of the respondents were owner/operators while the third was a sharemilker. In the Waikakahi catchment eight out of a possible thirteen dairy farmers were interviewed. Four farmers owned their farms, one with partners. There were also three types of manager: an operations manager, managing equity partner and general manager. One Waikakahi farmer was a sharemilker.

5.1.2 Current understanding and opinions of nutrient management

All of the eleven farmers interviewed had either a nutrient budget (NB) or a nutrient management plan (NMP) for their farm. Seven out of the eleven farmers had just a NB and four out of the eleven also had a NMP. Figure 5.1 illustrates that 18% of the farmers rated their nutrient budget or management plan as “not useful at all”. The farmers who rated in this way were from the Waikakahi catchment. The majority of farmers, 54%, gave a rating of 4/5 or higher indicating they did find their NB or NMP useful. The high ratings were from farmers in both catchments.

When asked how efficiently they thought they were using their nutrients 18% of the farmers believed they were using them very efficiently. No one believed they were not using them efficiently at all. The responses are illustrated in Figure 5.2. All of the farmers in the Inchbonnie catchment (three out of eleven) rated their efficiency as 3/5 indicating they thought they could be using their nutrients more efficiently. This is in contrast to the Waikakahi farmers the majority of whom rated their efficiency as a 4/5 or higher.

Figure 5.1. Distribution of responses to a question on the usefulness of nutrient budgets or management plan to farmers.

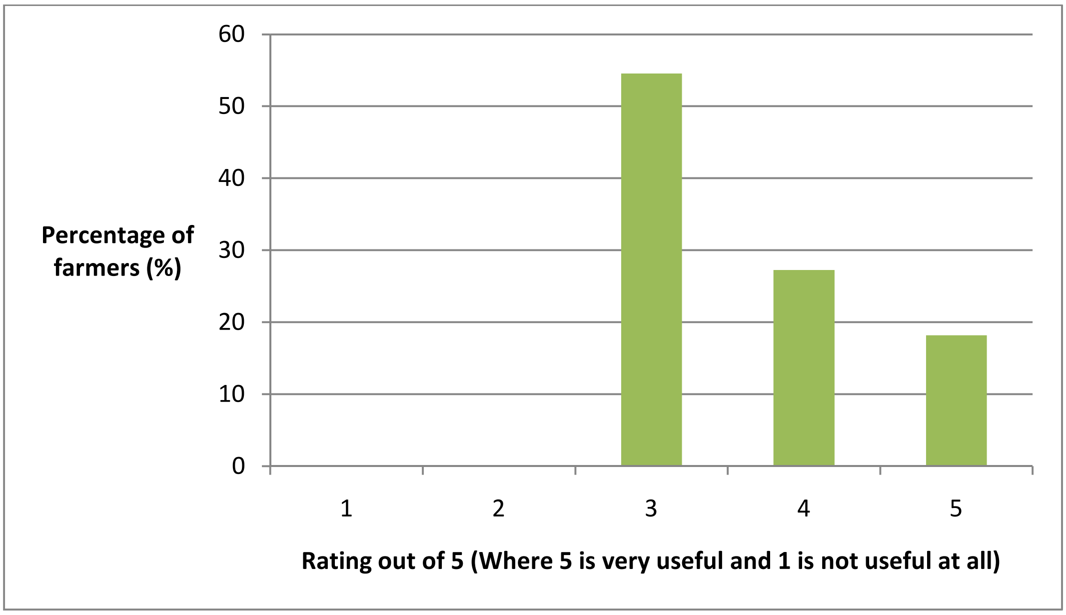

Figure 5.2. Distribution of responses to a question on how efficiently farmers thought they were using their nutrients.

Fertiliser and effluent application

Answers were coded with fertiliser and effluent application if they referred to applying fertiliser or effluent or referred to effluent storage. Planning and implementing fertiliser application is the main reason the farmers used NB and NMP's with seven out of eleven farmers making a reference to it in their responses. Of the seven farmers who use NB or NMP for fertiliser application, five referred back to the NB or NMP more than once a year. The seven farmers were a representative mix from both Waikakahi and Inchbonnie. Two farmers noted:

> Useful for setting up how much fertiliser is needed on farm -WK002
> To do initial fertiliser plan with Ravensdown -WK006

Three farmers use the NB or NMP for effluent application, two of whom were also farmers who use them for fertiliser application. They noted:

> To know where fertiliser is/has been. To know what nutrients are around from irrigation (IN002)
> Trying to stick within the thresholds we have set for how much. N especially is applied at low rate fertilisers. Don't apply huge amounts of N in urea. Try to manage the system to put less than 50kgN/ha from effluent. Have effluent tested quarterly -WK007

Three out of eleven farmers gave fertiliser as an aspect of efficient nutrient use. All three were from the Waikakahi catchment. One farmer noted:

> Making sure you are not using too much fertiliser and not having it run off -WK004

Two out of eleven farmers included effluent application as an aspect of efficient nutrient use:

> For a start good storage so you can apply when you want to apply effluent. Efficient use is spreading over the largest area you can at the smallest rate possible -WK007
> Tough question. Ideally, personally, I think you are better off using effluent as fertiliser as opposed to normal fertiliser. Has more beneficial nutrients and a bigger selection than normal fertiliser. Using it is efficiently using nutrients -IN002

Increase productivity, profits and efficiency

The code "increase productivity, profits and efficiency" was applied when farmers mentioned saving money or increases in production or efficiency as a reason to manage nutrients or achieve benchmarks. Four out of the eleven famers, all from Waikakahi were coded with increase productivity, profits and efficiency in the section on current understanding of nutrient management. One theme seen in responses throughout the survey was the linkage between environmental concerns and profits or profitability as the key to efficient nutrient use. This link is noted by two Waikakahi farmers:

> Oh you know protecting the environment and saving money for yourself- WK006
> Maximising profit and minimising detrimental environmental issues- WK008

This was not always the case. Profitability is considered by one farmer to be the main focus for efficient nutrient use, while another farmer considered productivity to be the main focus. They responded:

> Maximising profitability, how's that for an answer? WK002
> Maintaining soil fertiliser levels we have at the moment and applying what we need to achieve outputs, milk- WK001

Environmental concerns

Responses were coded "environmental concerns" if they referred to protecting the environment or having no detrimental environmental effects. Usually any environmental responses were explicit. Four out of the eleven farmers listed environmental concerns as a part of efficient nutrient use. All four farmers were from the Waikakahi catchment. The reposnses of two of them (WK006 and WK008) are included in the section on "increase productivity, profits and efficiency". The other two farmers refer to environmental concern as more of an add on after referring to efficient nutrient use and fertiliser overuse first:

> Probably good understanding. Making sure staff, and me as well, know what we are dealing with. Getting best use of nutrients we are using on farm not wasting anything we are putting on. As long as there are no environmental issues its good –WK003
> Not quite too sure, don't want to over fertilise or use too much to damage the country- WK005

The potential effect on the Lake Brunner catchment may drive the reduction of nutrient losses in the Inchbonnie catchment because of the value of the lake to the public. This driver is specific to the Inchbonnie catchment. Any mention of the water quality or environmental health of Lake Brunner was coded as an environmental concern. The benchmark that will be introduced in the Inchbonnie catchment will be designed to benefit the entire Lake Brunner catchment, not just Inchbonnie. Two out of three Inchbonnie farmers interviewed responded that in order to encourage farmers to meet the benchmarks the benefits to Lake Brunner need to be well documented, understood and scientifically sound. They elaborated:

> I would like to know what the P levels were in the lake 50 years ago, has it been altered significantly since dairy farms arrived? ... When dairy farmers benchmark other farm practices it is against dairy farmers who have been doing it for 50-60 years-need to do this with these benchmarks and lake water quality data. Give everyone an idea where the lake sits in the scheme of things so you can see effects due to dairy farms and then can figure out what we have to work towards. What else is going in the lake? IN002
> Need to build up sound picture of what is happening in Lake Brunner catchment. Don't doubt the information that the hydrologist is giving via regional council, it is soundly based. But we do need to know [that] it is [especially] given the extent to which it may require changes, need to be little doubt of benefits or all changes are for nothing- IN001

This concern was also raised in the Inchbonnie farmer and industry meeting on 20 July, 2011. Farmers raised questions regarding: What is the biggest source of P loss to the lake from farms? What are the results of recent lake water quality tests? What other than P loss reduction is important to the lake as we only want to make large on-farm changes once?

Regulation/ resource consent

The "regulation/resource consent" code was applied when farmers mentioned regulatory enforcement when talking about nutrient management. It was also applied when consents or regional councils (Environment Canterbury or West Coast Regional Council) were referred to either directly or indirectly. NB and NMP's are viewed by some farmers as a "*license to farm*" *–IN003* but otherwise not at all helpful. One farmer noted:

> Handy document for other people to understand what you are doing on farm, I already know what I am doing –WK002

5.1.3 Understanding and opinions of the nutrient benchmarks

The farmers were asked to rate how useful it would be to them to have a benchmark that indicated a target for efficient nutrient use and how useful it would be to have a benchmark that indicated an N loss or P loss target. No one gave a rating lower than 3/5 as illustrated in Figure 5.3. This indicates they all believe the benchmarks would be of some use. The majority, 64%, rated the usefulness of both benchmarks as 5/5 or very useful. One farmer in the Waikakahi catchment rated the usefulness of a nutrient loss benchmark higher than a nutrient use efficiency benchmark. The other ten farmers gave both benchmarks the same rating.

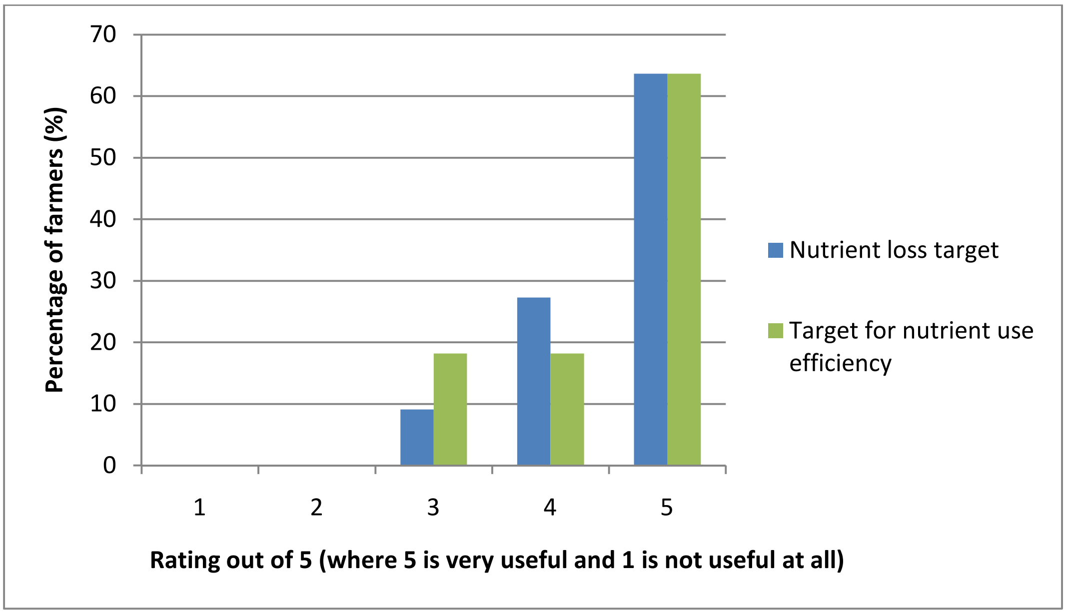

Figure 5.3. Distribution of responses to a question on how useful it would be to have benchmarks which set targets for nutrient loss or nutrient use efficiency

Increase productivity, profits and efficiency

The code "increase productivity, profits and efficiency" was applied when farmers mentioned saving money or increases in production or efficiency as a reason to manage nutrients or achieve benchmarks. It was established through the interviews that increasing production, profits or efficiency, would incentivise the achievement of benchmarks for three out of the eleven farmers all from Waikakahi. Two of these farmers noted:

> Knowing we were saving money but not losing the nutrient- WK001
> Proven profitability- WK002

Environmental concerns

As in the current understanding of nutrient management section, responses were coded with environmental concerns if they referred to protecting the environment or having no detrimental environmental effects. In this section it also refers to potential environmental benefits from benchmarks. Only three out of eleven farmers were coded with environmental concerns being a reason that nutrient efficiency or loss benchmarks would be useful. WK008 rated the usefulness of the efficiency benchmarks as a 4/5. His reasoning was that it would be useful to have clarification of aims from an environmental point of view. Two of the Waikakahi farmers rated the loss benchmarks highly (4/5 and 5/5). WK003 focused particularly on the environmental concern whereas WK001 linked both profit and environment:

> Those are the two biggies in the environmental area. If we can minimise these two losses gotta be good for everyone. Especially here having a creek on farm- WK003
> Definitely for N loss. Obviously I don't want to spend money on something that is not being used and if not being used it is going somewhere it's not meant to, maybe polluting- WK001

Even though they did not mention the benchmarks would be useful due to environmental concerns the majority of the farmers (seven out of the eleven) replied that environmental concerns would drive them to meet or achieve the benchmarks. Two farmers, one from each catchment, wanted to achieve the benchmarks purely to ensure they were not causing a problem to the environment. They noted:

> Passion for the environment. Don't like to see dirty dairying. At the end of the day it does not have to be like that at all. - IN002
> Know that I am using it properly so I am not causing a problem to the environment- WK004

Four of the farmers responded that the cost as well as the environmental benefits would drive benchmark achievement. In every answer cost effectiveness, reduction in compliance costs or money saving was listed ahead of environmental concerns. The answers ranged from definite responses such as:

> Two things: use of resources-so saving money and time applying them and saving equipment. Secondly the environmental outcome- IN001

to the less definite answers as noted:

> Not quite sure, knowledge of money saved and the environmental benefits? - WK005

Current guidelines and practices

This code was assigned when an aim or target was mentioned, whether it was that the current aims or targets are too vague or that there is the need or room for an aim or target now. It was also assigned when variation in practice between farms was mentioned as this was seen as a result of the current guidelines. Five out of the eleven farmers were assigned this code. Three out of the five farmers (two from Waikakahi, one from Inchbonnie) rated the usefulness of the benchmarks high (5/5, 5/5 and 4/5) because it gives a figure with which you can quantify the nutrient management on your farm and adjust accordingly. Two farmers elaborated on their ratings:

> Really important because it will give us something to aim for and to see improvements- WK006
> If we have information that gives us definite targets (as we do not have those targets now) we would be able to quantify what we do/don't do- IN001

Two of the eleven farmers, one from each catchment, believe that the benchmarks rate low on a scale of usefulness (3/5) or would not drive any on farm changes due to the variation in farm practices. For IN003 the variation was between regions as elaborated:

> [In this catchment] costs are above the average for fertiliser usage, we're looking at lowering the costs but keeping the efficiency, especially compared to Waikato where they don't have to apply much urea at all. Lack of sunlight as well, it is cloudy when it is not raining, we need to artificially grow grass to maintain feed- IN003

In contrast, WK002 was concerned about variation between farms in the same region:

> Variability of farm practices. Unless you understand what other farmers are farming around you. If you are below or above you need to understand why you are below or above- WK002

Regulation/ resource consent

The regulation/resource consent code was applied when farmers mentioned regulatory enforcement to do with nutrient management or benchmarks. Responses from four out of the eleven farmers, three from Waikakahi and one from Inchbonnie, were coded with regulation/resource consent. Both IN002 and WK007 had positive opinions. WK007 answered that the benchmarks would be useful as they could know that if you were meeting the benchmarks that you are at the highest possible standard and should meet consent conditions. IN002 had a logical view on rules set by regional councils, noting:

> We all have rules that we live under and we need to comply with these rules- IN002

In contrast WK008 indicated they would not meet the benchmarks unless forced to particularly if the proposed benchmarks would reduce production. He noted:

> Have to be regulatory enforcement of some description. Depends if it gets to a level where what we are doing is potentially reducing production. If N or P are capped by stocking rate or fertiliser application at levels that reduce production we would make changes education is the key in that – WK008

WK002 had a strong opinion on the potential stance the regional councils may take with benchmarks. He noted:

> Benchmarks are incredibly dangerous. ECan [Environment Canterbury] can pick them up and apply them with no rhyme or reason. As soon as this gets put in place and you don't meet them you are forced to do practices not better than what you are already doing- WK002

It was unclear if he was referring to a specific example with this response and he did not elaborate.

Peer pressure/ community views

This code was applied when farmers indicated that the reason for doing a particular practice was either due to peer pressure of the view of outsiders. Four out of the eleven farmers had answers that were coded with this, all from the Waikakahi catchment. WK004 and WK006 used similar phrases to describe why the view of outside parties would make efficiency benchmarks useful. They were:

> Well you gotta be seen to be efficient, you don't want to be seen to be inefficient or you are not getting value for money- WK004

> You gotta be environmentally conscious as there are a lot of outside interests to farming who want us to be environmentally friendly- WK006

WK002, as a final comment, indicated that peer pressure, or views within the farming community, of people who overachieved and pushed the benchmark higher would affect the success of the benchmarks. The consequences that opinions like this may have on the benchmarking project will be elaborated on in Chapter 6. He notes:

> (A farmer) rang the other day and asked if he should do something. I said no because If you do it right you will set a standard and the neighbours will hate it and If you don't do it right you will be below not meet the standards and will have spent a lot of money for no reason- WK002

Understanding, education and behaviour change

This code was assigned when the responses referred to understanding, knowledge or education as important to nutrient management and the potential for benchmarks to drive behaviour change. The need for understanding is only referred to by one farmer, from Waikakahi, in the first section on current understanding of nutrient management as an important element of efficient nutrient use. Four out of eleven farmers, three from Waikakahi, were coded with understanding, education and behaviour change in this section. Two farmers indicated that understanding and knowledge will be important in helping to encourage them to meet the benchmarks. They note:

> Understanding of what we are dealing with. What we are trying to achieve is obtainable, Cost effective. Good for the environment then I am all for it- WK003
> Know that I am using it properly so am not causing a problem to the environment- WK004

IN002 believed that if the benchmarks were achieved they would provide an opportunity to learn. This belief ties into his previous comments that a passion for the environment would drive benchmark achievement. IN002 notes:

> Yes, we can learn from them especially if they fit into farming practice. We want this farm to be a model farm and that is our aim for the next 3 years. We push to solve environmental issues on properties we have been on. My driving force is having a farm that WMP or Fonterra can walk into and say this is best practice. Foundations for this are on the farm in Inchbonnie and we are open to learning to achieve this- IN002

WK007 was the only farmer out of the eleven interviewed to indicate recognition that the benchmarks were a tool that would be introduced to encourage behaviour change. He notes:

> Ultimately if the benchmarks are introduced. Always going to look at where you are versus the benchmark. This will drive behaviour. If someone points it out and why you are below it you will need to improve so not the outlier in the immediate area. Benchmarks have always been used by companies to improve behaviour. Encourages the good to strive harder- WK007

5.1.4 Summary

The current understanding and opinions of nutrient management and nutrient benchmarks have been presented in terms of the themes used in the coding of the interview data. These themes will be discussed comprehensively in the next chapter with respect to whether they indicate the farmers will implement the nutrient benchmarks. This section is followed by the water quality modelling results which determine if the benchmarks discussed in the interviews will improve water quality.

5.2 Results of water quality modelling

This section begins by presenting the results of Scenario One which is an initial comparison between the predicted current situations modelled in CLUES and the measured water quality from Wilcock et al (2007). This comparison indicates the factor of difference between the predictions and measurement. This is followed by the results of Scenario Two which is the predicted water quality after the introduction of the proposed water quality benchmarks. The improvements in water quality as a result of the benchmark are compared to two guidelines per catchment to determine if they will achieve water quality targets. The resulting TP concentration in Lake Brunner as a result of introducing the P loss benchmark to its main tributaries is also presented. This TP concentration is compared with proposed TP values to determine if the benchmarks will achieve water quality aims in the wider Lake Brunner catchment.

5.2.1 Scenario One: comparisons between the current water quality predictions and measured water quality

Table 5.2 presents the comparisons between the predictions of current TN for the Waikakahi catchment from CLUES and the measured TN from Wilcock et al (2007). There is fairly close agreement in the Waikakahi catchment between the predicted and measured TN loads, concentration and flow. The original TN yield calculated by Wilcock et al. (2007) was 8.1 kgN/ha/yr. This is much larger than TN yield predicted by CLUES. It suggests that CLUES underestimates TN yield in the Waikakahi catchment by a factor of 2.8. The TN yield from Wilcock (2007) was calculated by dividing TN load by the area. The apparent underestimation of TN yield may then be a result of the area used by Wilcock et al (2007) in this calculation. The CLUES area, 136.2 km², takes into consideration the hill area which is a part of the hydrological catchment whereas the area used by Wilcock et al. (2007) area, 41km², only includes the Best Practice Dairy Catchment area. When the Wilcock et al. (2007) TN load is divided by the entire catchment area the result is a yield of 2.4 kg/ha/yr as presented in Table 5.2. This means there is also reasonably close agreement between the predicted and measured TN yields in the Waikakahi catchment.

Table 5.2. CLUES predictions of TN and comparative TN measurements from Wilcock et al. (2007) using the 136.2 km² area in the Waikakahi catchment.

	Predicted	Measured Wilcock et al. (2007)
TN Load (t/y)	39.3	33.2
TN yield (kg/ha/yr)	2.9	2.4
TN concentration (mg/m^3)	2244.2	2340.0
Area (km^2)	136.2	136.2
Flow (m^3/s)	0.555	0.537

Table 5.3 describes the comparisons between the predictions of current TP from CLUES for the Inchbonnie catchment and the measured TP from Wilcock et al (2007). The flow predicted by CLUES and the flow measured by Wilcock et al. (2007) are very different. The predicted flow is 1.8 times larger than the measured flow in the catchment. The key reason for this difference lies in how CLUES has calibrated flows from much larger catchments which will be discussed in Chapter 6.

Table 5.3. CLUES predictions of TP and comparative measurements from Wilcock et al. (2007) in the Inchbonnie catchment.

	Predicted	Measured Wilcock et al. (2007)
TP load (t/y)	1.62	3.01
TP yield (kg/ha/yr)	3.06	5
TP concentration (mg/m^3)	72.61	132
Area (km^2)	5.3	6
Flow (m^3/s)	0.707	0.396

There is a poor match between predicted and measured TP values in the Inchbonnie catchment (Table 5.3). TP load and concentration are underestimated by factors of 1.8 and TP yield by a factor of 1.63. These factors are within the 75th to 90th percentile range of error factors evaluated for TP predictions in CLUES (Elliott et al., 2011). Yield and load calculations in CLUES are not calculated using flow so the difference in flow would not have caused this disagreement. The reasons for the differences in TP load and yield may partially lie in the calibration of the CLUES model which will be discussed in Chapter 6.

Table 5.4. Results of the CLUES predictions of TP from this research compared to results of modelling by Parshotam and Elliott (2009) using an earlier version of CLUES in the Inchbonnie catchment

	Parshotam & Elliott (2009) using default values	Parshotam & Elliott (2009) with additional dairy term	This research
TP Load (t/y)	1.08	3.70	1.62
TP yield (kg/ha/yr)	2.03	6.9	3.05
Flow (m^3/s)	0.606	0.606	0.707

Parshotam and Elliott (2009) modelled the BPDCs using a previous version of CLUES (version 2.0.6) which included an additional dairy term. This additional dairy term compensated for the P loss from dairy farms which the CLUES model does not include. The TP load and yield predicted in this research are similar to the default predictions by Parshotam and Elliott (2009) but not the predictions with the additional dairy term (Table 5.4).

At this point, there will not be an N loss benchmark established for the Inchbonnie catchment or a P loss benchmark established in the Waikakahi catchment. This makes agreement between predicted and measured TN in the Inchbonnie catchment or TP in the Waikakahi catchment inconsequential to the modelling results in this research. The impact of the omission of these benchmarks to the overall benchmarking project will be discussed in Chapter 6.

5.2.2 Scenario Two: comparisons between the water quality predictions with nutrient benchmarks and water quality values

N loss benchmarks in the Waikakahi Catchment

The Waikakahi catchment was modelled with an N loss benchmark of 24 kgN/ha/yr. The introduction of the N loss benchmark resulted in a small improvement in TN levels in the catchment as illustrated in Figure 5.4. There was a 15% decrease in TN load and consequently TN yield and TN concentration (Table 5.5).

Table 5.5. Current TN values in the Waikakahi catchment compared with TN values in the Waikakahi catchment after the introduction of the benchmark reducing N loss by 33%. The results are modelled predictions from CLUES 3.1.

	Scenario One: Current prediction	Scenario Two: Benchmark prediction
TN load (t/y)	39.30	33.27
TN yield (kg/ha/yr)	2.90	2.43
TN conc (mg/m^3)	2243.9	1899.6

The ANZECC (2000) guideline for TN is a concentration of 0.614 mg/L or 614mg/m^3. After the introduction of the N loss benchmark, CLUES predicts an absolute TN concentration for the Waikakahi catchment of 1899.6 mg/m^3 which is much higher than the ANZECC (2000) guideline. It is however below the Environment Canterbury (2009) nitrate toxicity guideline which was calculated to be a TN value of 2.10 mg/L or 2100 mg/m^3.

The relative change between Scenario One and Scenario Two predictions for TN concentration is a 15% decrease. The measured TN concentration in the Waikakahi stream after the introduction of benchmarks may then be a 15% reduction of the measured TN concentration from Table 5.5. This would result in a TN concentration of 1989 mg/m^3 which is in the zone that would trigger concern under the ANZECC (2000) guidelines but it is below the Environment Canterbury (2009) nitrate toxicity guidelines.

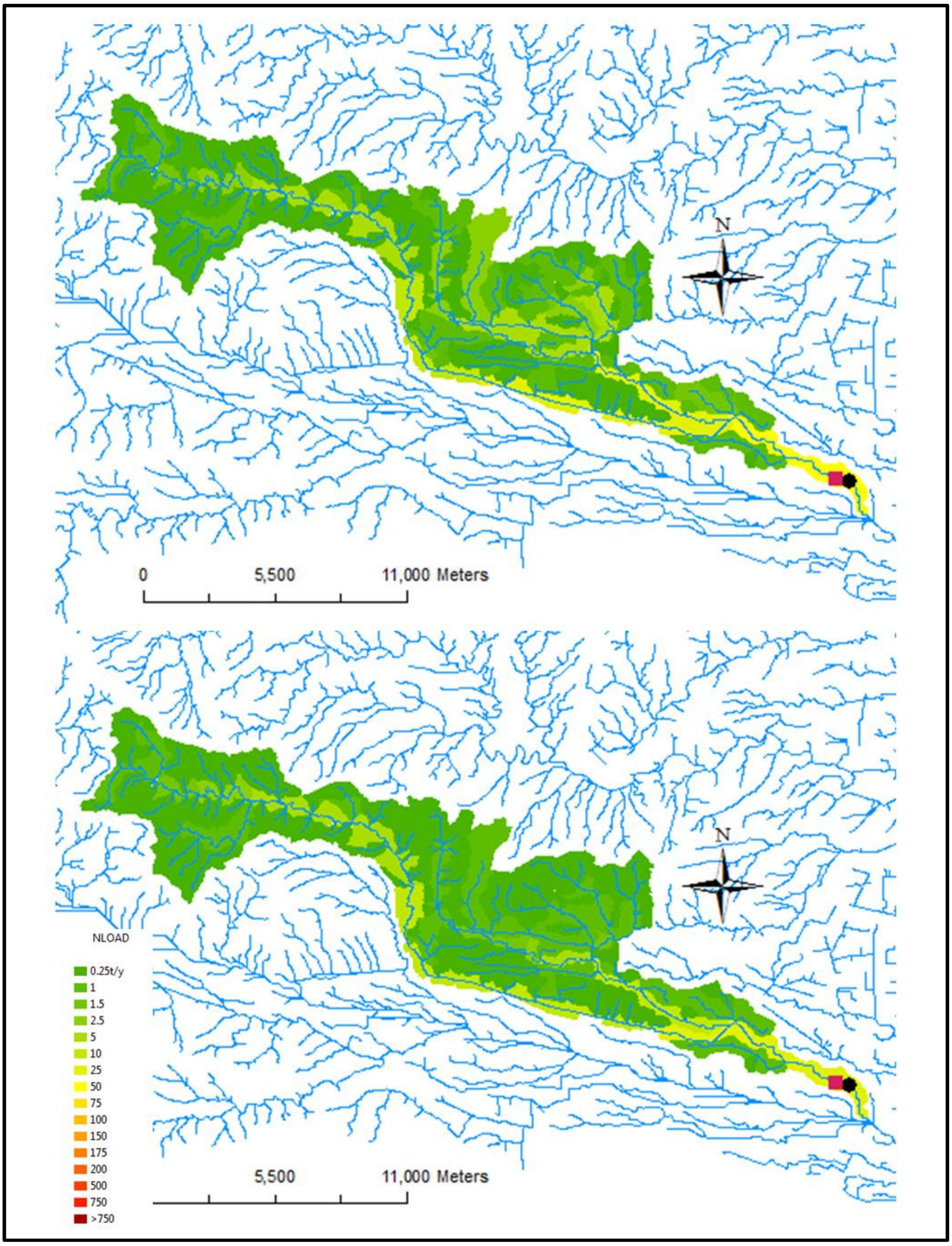

Figure 5.4. The Waikakahi catchment showing the difference between the current TN load, on the top, and TN load with the N loss benchmark reduction of 33% on the bottom. The pink square toward the right of the catchment plume is the outlet of the Waikakahi Creek into the Waitaki River at State Highway 1. Note the reduction in N load particularly in the central Waikakahi catchment depicted by more green tones than yellow.

P loss benchmarks in the Inchbonnie Catchment

The Inchbonnie catchment was modelled with a benchmark that reduced P loss by 0.65 kg/ha/yr. Table 5.6 shows that when the P loss benchmark was modelled in the Inchbonnie catchment an improvement occurs to the TP levels. The reduction in TP load is illustrated in Figure 5.5. The introduction of this benchmark resulted in a 21% reduction in TP yield and TP load. There was consequently a similar reduction in TP concentration as presented in Table 5.6.

Table 5.6. Current TP values in Inchbonnie Catchment compared with TP values after the introduction the P loss reduction benchmark of 0.65 kgP/ha/yr. The results are modelled predictions from CLUES 3.0.

	Scenario One: Current prediction	**Scenario Two: Benchmark prediction**
TP Load (t/y)	1.62	1.28
TP yield (kg/ha/yr)	3.06	2.41
TP conc (mg/m³)	72.79	57.37

The ANZECC (2000) water quality guidelines set a TP concentration limit of 0.033mg/L or 33 mg/m³ as discussed in Chapter 4. The absolute TP concentration in Inchbonnie predicted by CLUES after the introduction of the 0.65 kgP/ha/yr benchmark is 57.37 mg/m³. The relative change between the Scenario One and Scenario Two TP predictions is a 21% reduction. If the measured TP concentration from the Inchbonnie catchment from Table 5.3 is reduced by 21% the TP concentration after the benchmark is introduced would be 104 mg/m³. This TP concentration is above the ANZECC (2000) guidelines for TP concentration, within the range of concern.

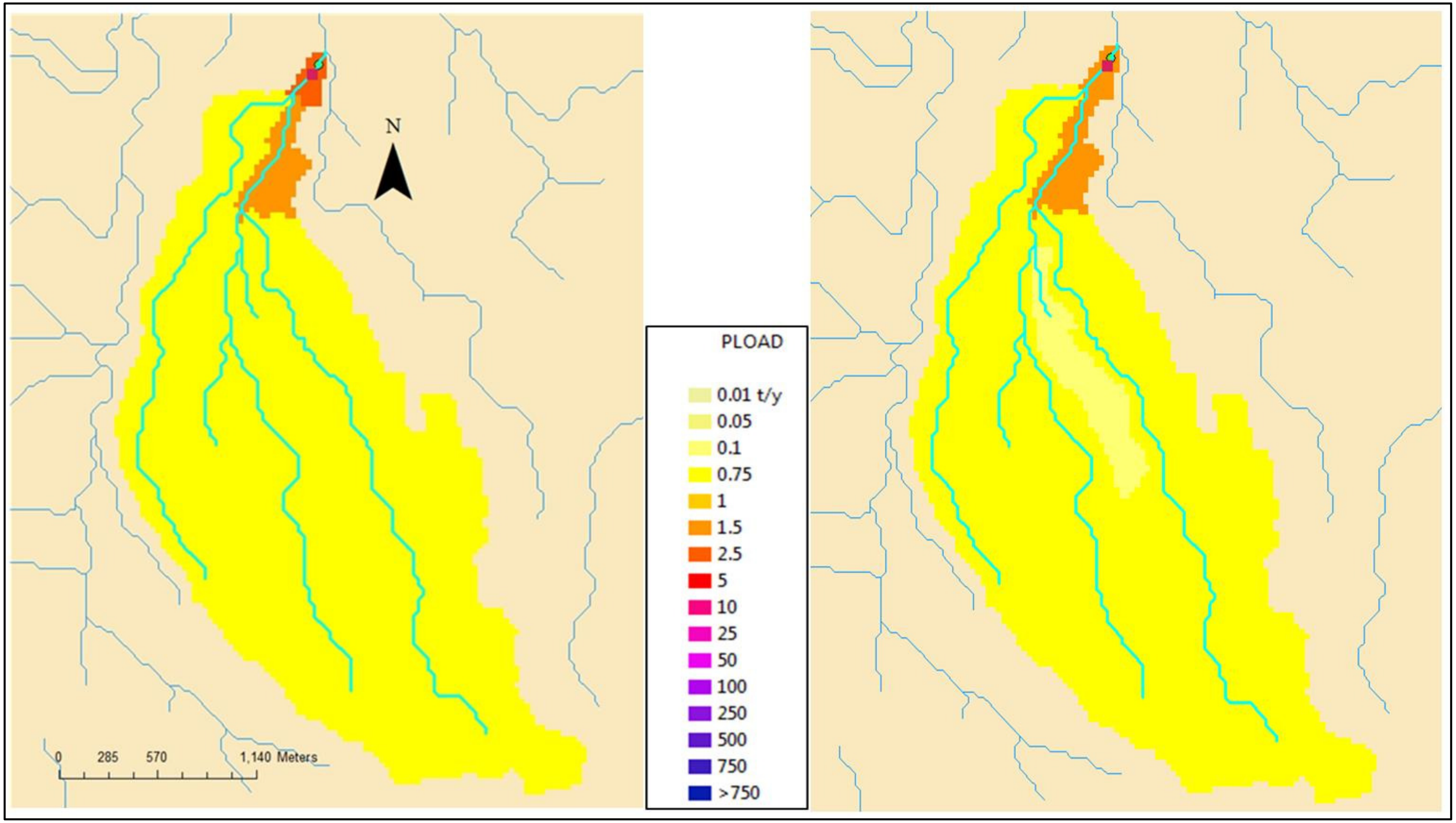

Figure 5.5. The Inchbonnie catchment showing the difference between the current TP load, on the left, and TP load with the introduction P loss benchmark on the right. The pink square toward the top of the catchment plume is the outlet of Pigeon Creek into Bruce Creek. Note the reduction in TP load particularly at the final reach of the catchment.

5.2.3 Results from the Lake Brunner Catchment

The 0.65 kgP/ha/yr reduction benchmark was also introduced to the three main tributaries of Lake Brunner illustrated in Figure 4.11. Table 5.7 displays the results of this modelling. The Scenario One values are the result of running the default scenario for the catchments through CLUES. TP yield, the initial water quality value calculated by CLUES, is overestimated in all three catchments. The Crooked and Hohonu Catchments are overestimated by factors of 3.06 and 3.42 respectively. The TP yield in the Orangipuku Catchment is overestimated by a factor of 1.73.

Table 5.7. Results of the CLUES modelling of the three main catchments contributing to Lake Brunner. Measured values come from Rutherford et al (2008).

	TP yield (kg/ha/yr)		
	Measured Rutherford et al. (2008)	**Scenario one: predicted Default**	**Scenario two: predicted benchmark**
Crooked River	0.59	1.81	1.73
Hohonu River	0.19	0.65	0.64
Orangipuku River	0.93	1.61	1.34

	TP concentration (mg/m³)	
	Scenario one: predicted Default	**Scenario two: predicted benchmark**
Crooked River	52.76	50.12
Hohonu River	19.15	18.43
Orangipuku River	42.15	35.01

The mean TP concentration of all the inflows to Lake Brunner is 12.5-13.5 mg/m³ and should be equal to the mean TP concentration of the three catchments as they contain the majority of the TP sources to the lake (Verburg, 2009). The average of the predicted default TP concentrations of the three catchments is 38.02 mg/m³. This indicates that TP concentrations are overestimated in the catchment by CLUES by a factor of 3.04.

The introduction of the P loss benchmarks reduced the TP yield and TP concentration in all three catchments (Table 5.7). The Orangipuku catchment had the largest reduction, with a 17% decrease. The Hohonu catchment had the smallest reduction; this is probably due to the small volume of dairy farming in that catchment. The average predicted TP concentration after the benchmarks is

34.52 mg/m³. The relative change between Scenario One and Scenario Two is a 7% reduction in the TP concentration from the catchments entering the lake.

The mean concentration of the three rivers from Verburg (2009) of 13.5 mg/m³ was entered into Equation 4. This determined that P currently contributed to the lake from the catchments is 6.52 mg/m³. The relative change predicted by CLUES, a 7% reduction, results in 5.27 mg/m³ of P contributed to the lake from the Crooked, Hohonu and Orangipuku catchments following the introduction of the P loss benchmark. This calculation has assumed the three modelled catchments provide the majority of the TP source entering Lake Brunner. There may be additional TP concentration added from the remaining areas of the catchment. It is unlikely that this additional TP concentration would raise the total TP concentrations to above 7 mg/m³. Therefore it appears that the introduction of the P loss benchmarks to the entire Lake Brunner catchment will improve the TP concentration in the lake, keeping it below the proposed TLI guidelines.

5.3 Conclusion

The CLUES model does not predict TP or TN results in close agreement with the measured values for any of the Waikakahi, Inchbonnie or Lake Brunner catchments. However, previous research has indicated that the overall trends in loads and concentration predicted by CLUES are credible (Monaghan et al., 2010). As a result the absolute values predicted in CLUES are viewed in that context. The modelling suggests the introduction and achievement of P loss benchmarks in the Inchbonnie catchment and N loss benchmarks in the Waikakahi catchment will result in a reduction in the associated nutrient loads. It would not be enough to be within the ANZECC (2000) guidelines. If the benchmark were to be applied across the Lake Brunner catchment it would allow the achievement of the TP aspect of the proposed TLI for the lake. These results will be discussed in detail along with results from the farmer interviews and other literature in the next chapter

Chapter 6 Discussion

6.1 Introduction

Three research questions were outlined at the beginning of this study. The results of the mixed methods presented in Chapter 5 and the literature explored in Chapters 1, 2 and 3 are discussed in this chapter with respect to the final two research questions. This discussion will help to answer the main research question in the concluding chapter: “Will the nutrient benchmarks help to achieve sustainable milk production systems in the two contrasting catchments?”

6.2 How do farmers in the Best Practice Dairy Catchments interpret the benchmarks?

Interviews with the BPDC farmers determined that while they were generally positive about the usefulness of benchmarks in their catchments their interpretation of them varied. Knowledge of environmental and economic benefits emerged as the key themes relating to nutrient management and nutrient benchmarks. However, other qualitative aspects need to be taken into consideration, such as the extent to which these key themes influence farmers’ interpretation of the benchmarks as well as the need to increase farmers’ knowledge around nutrient flows on farms. These aspects have the potential to affect both the key themes and how the farmers interpret the benchmarks.

6.2.1 Main themes for driving benchmark achievement

A definition for a sustainable milk production system is defined in Chapter 3 independent to the interview analysis. The definition states a sustainable milk production system is one that is able to meet the current economic needs of the farmer as well as maintain the social/cultural and environmental values that reside in the place where the farm system is located. Two of the main themes that the farmers interviewed in this research perceived as potential drivers of benchmark achievement were closely related to this definition. These themes are environmental concern and the economic needs of the farmer, through increases in profit, production or efficiency.

Seven out of the eleven farmers reported the theme environmental concern or environmental benefits in relation to nutrient benchmarks. It is easy to speculate that “environmental benefits” may be a standard response from BPDC farmers to any line of questioning around nutrient management, particularly when a previous study in the catchments determined that attitudes to sustainability and the environment had a very limited part to play in their consideration of improved nutrient management practice (Bewsell & Kaine, 2005). However, the majority of the farmers interviewed revealed an understanding of the concepts behind the environmental benefits of the benchmarks. One Waikakahi farmer noted that reducing nutrient loss would be beneficial to creeks on the farm, while another noted that if the nutrients are not going where they are meant to be they are probably polluting. The Inchbonnie farmers demonstrated an understanding of phosphorus loss sources and the relationship between their catchment and Lake Brunner water quality in both the interviews and in the farmer meetings. It would be beneficial in future interviews to include questions that clarified or expanded on specifically what the environmental outcome or environmental benefits are seen to be and how that would affect benchmark achievement. They were not included in this interview and would help to define the farmers' environmental concerns.

Economic benefits through an increase in profit, production or efficiency is the other main theme that emerged from the interviews. Six out of the eleven farmers mentioned this as potentially driving their benchmark achievement. The current process used in the Inchbonnie catchment to develop a benchmark determines the cost efficiency of the mitigation measures on farm (S. Hayward, personal communication February 1, 2012). The financial benefits of reducing P loss do not always meet the expense of installation or achievement of the mitigation measure. In some catchments or on some farms the decreases that need to occur will be large. The scale of mitigation may then come at a large financial cost to the farmer.

Throughout the past decade of monitoring and research in the five BPDCs there have been gradual reductions in farm outputs of nutrients through changes in farm management practices particularly through decreasing fertiliser inputs (Campbell et al., 2010; Monaghan et al., 2009b). Other changes on farm include stock exclusion fencing, >95% of waterways within New Zealand dairy catchments are fenced as well as riparian planting of some of the more vulnerable areas and protection of significant wetlands (Fonterra, 2011a). These changes have significantly reduced sediment losses but have not resulted in significant reduction in nutrients lost to waterways in the Inchbonnie or Waikakahi catchments (Monaghan et al., 2009b). In the Waikakahi catchment between 30-50% of border-dyke irrigation has been upgraded to become more efficient which has reduced wipe-off water generation and losses to adjacent streams. There has been less uptake of other possible mitigations such as Olsen P optimisation and nitrate inhibitors as well as large scale mitigations such as effluent system upgrades and wintering sheds in the two BPDCs (Monaghan et al., 2007a). The reasons for which are likely related to cost, complexity and compatibility with current farm systems. The positive view of the benchmarks currently expressed by the farmers in this research may change (be viewed negatively) if the economic cost of meeting the benchmarks is large.

A major difference between the two catchments is that in the Inchbonnie catchment public concern over the water quality of Lake Brunner is an external influence driving nutrient management. Two of the three Inchbonnie farmers interviewed noted the lake when discussing the introduction of the benchmarks in the region. The Waikakahi farmers do not have a similar nutrient-related driver in their catchment. This is because historically the public and media interest has been around the effect of sediment and stock access on the Waikakahi stream health (Meredith et al., 2003). The key values identified in *Best Practice Dairy Catchments study* (2009b), particularly a clear channel for drainage, were never mentioned by any of the Waikakahi farmers as driving the need to improve nutrient management. It is likely that this is because those key values are, to the farmers, associated with excess sediment and stock access to rivers, not nutrients. The current lack of an external influence encouraging the nutrient benchmark achievement in the Waikakahi catchment may hinder their success in this catchment.

6.2.2 Nutrient budgets predominantly used for fertiliser application

How the farmers are currently using their nutrient budgets has the potential to impact on the success of the nutrient benchmarking project. While farmers may currently view the benchmarks as a positive concept it is possible that the current utilization, or lack thereof, of nutrient budgets will impact on farmers implementation and understanding of the benchmarks. Monaghan et al. (2007a) argued that the advancement of nutrient budgeting tools, like OVERSEER, have progressed nutrient management decisions on farm. They enable farmers to include all nutrient transfers on the farm not just fertiliser applications when making decisions.

This argument did not prove to be true of the Inchbonnie and Waikakahi farmers who still use their nutrient budgets predominantly for planning fertiliser application. When the fertiliser representatives establish the nutrient budgets they do take all inputs into consideration however, this is not noted by any of the farmers. Only two of the eleven farmers, one from each catchment, indicated the progressive decision making described by Monaghan et al. (2007a). These two farmers used their nutrient budgets for a combination of both effluent and fertiliser application as well as general awareness of nutrients and referred back to their nutrient budgets on a regular basis through the year. The majority of the farmers rarely referred to their budgets after they were annually established with their fertiliser representative. Nutrient budgets are required by all Fonterra suppliers under the Dairying and Clean Streams Accord (2003), which is relevant to the Waikakahi catchment. They are also required by Westland Milk Products under the Environmental Code of Practice (2011), which is relevant to the Inchbonnie catchment. None of the farmers noted these as a use for their nutrient budgets. It is likely that further education around nutrient flows through farms, as well as the introduction of the nutrient benchmarks which provide an indication on what *good* nutrient management looks like, may help to incentivise better nutrient management and encourage the use of nutrient budgets and nutrient management plans. This needs to be addressed in order for the benchmarks to be successful.

6.2.3 Additional qualitative aspects of the introduction of nutrient benchmarks in the Best Practice Dairy Catchments

It became apparent during both the background research and observations during the interview process that the introduction of the benchmarks involves other qualitative aspects. It was important to gain a professional relationship between the researcher and the farmers. This was achieved by forewarning the farmers that the interviews were occurring as well as by attempting to contact prominent farmers first to build a rapport. Without doing this dairy farmers in the catchments may not have been as willing to complete the interviews.

The value that dairy farmers put on the opinion of other dairy farmers was also perceptible in the interviews. One farmer noted that he had advised another farmer against upgrading a farm system because if they do it right they would set too high a standard for the neighbours and if they do it wrong they would be below future standards and would have spent a lot of money for no reason. In the preamble to the interview with IN003 he mentioned that following the July 2011 Inchbonnie farmer and industry meeting he had spoken with another farmer in the catchment about the benchmarks to gain clarification around them. He did not want to seek the advice of any of the industry professionals. Some of the farmers had strong opinions about the development and future of benchmarks. WK002 for example described the benchmarks as incredibly dangerous and was concerned that Environment Canterbury would include them in regulation as a minimum standard.

It may not necessarily be the opinion of a particular farmer that will convince the rest, it may be a farmer's action or inaction. If one farmer achieves the benchmark and promotes his success in the catchment he may be influential in convincing others to achieve it. Conversely if a farmer, who is known to have poor nutrient management does not attempt to meet the benchmark and promotes his inactivity within the catchment, others may decide not achieve the benchmark. Their positive impacts would be undermined by his negative impacts. As noted by WK003 the benchmarks would work better if everyone is participating. The success of the benchmarks in these catchments may be dependent on knowing who these farmers will be and engaging their support early in the benchmark process. It is likely that DairyNZ will already have knowledge of who these farmers are because of the BPDC project.

6.2.4 Limitations of the telephone interviews

The final sample size for the interviews was 65% of the population which was a good response rate. However, it consists of only 11 farmers out of a potential population of 17. The small sample and population made statistical analysis difficult because it could not be assumed that the results from the interviews were normally distributed. It also increased the potential for individual farmers to be identified from demographic information such as farm or herd size which is common knowledge among neighbouring farmers. This reduced the ability to make inferences between the demographic attributes and opinions in the results.

The Inchbonnie and Waikakahi catchments were ideal study areas for this research because of their involvement in the BPDC project. Conversely because of the BPDC project they have had heightened awareness and education regarding environmental issues which may have introduced an element of bias into their attitudes (Mackay & Smith, 2010). This education includes the identification of the key environmental issues in the areas and practices that could reduce these issues. It has made the BPDC farmers some of the most environmentally knowledgeable farmers in the country; this information is not available for, or in, every dairy catchment in New Zealand (Scarsbrook, 2011a). This potential bias limits the ability to make generalisations about the entire New Zealand dairy farming population from the survey results. Making general assumptions about the success of nutrient benchmarks from the interpretation of the BPDC farmers was not the aim of this research but may be useful to the DairyNZ benchmarking project. The assumptions will need to be gauged on other farmers before they are relied on to implement the benchmarks nationwide.

6.3 How effective are the benchmarks in improving water quality in the catchments?

6.3.1 Water quality improvements as a result of the benchmarks

Introduction of the benchmarks did improve the water quality in both catchments. TN concentration predictions in the Waikakahi catchment and TP concentration predictions in the Inchbonnie catchment were less in Scenario Two-benchmark water quality predictions than Scenario One-current water quality predictions, resulting in an improvement in water quality. It is assumed that a reduction of nutrients lost on farms in a catchment would result in a reduction of nutrients in the waterway of the catchment and a related improvement in water quality. It is more important to the success of the benchmarks that the improvement is significant enough to protect the key values in the catchments. Scenario Two predictions were compared to two guidelines for each catchment to determine their significance.

The potential improvement in water quality in both catchments was not enough to reduce the Scenario Two nutrient concentrations to levels that were under the trigger values for protection of slightly disturbed ecosystems in lowland rivers (ANZECC, 2000). This means that the introduction of benchmarks did not significantly improve the TN concentration in the Waikakahi catchment or the TP concentration in the Inchbonnie catchment to levels that provide confidence that they are supporting ecological values. Having said that, the ANZECC (2000) target values are considered environmentally conservative particularly for streams which flow through such fertile land (Ministry for the Environment, 2009). As discussed in Section 4.2.3 Scenario Two: water quality predictions with benchmarks, failure to achieve these guidelines indicates there is a need to derive regional water quality limits that are appropriate and realistic for the catchments. Comparison to regionally derived targets was sought in order to better determine the successful of the benchmarks.

TN concentrations in the Waikakahi catchment were compared to a TN concentration that is related to detrimental nitrate toxicity levels. The TN concentrations in the catchment following the benchmark introduction achieved this guideline threshold. Therefore the TN concentration post-benchmark would not threaten sensitive fish species, but may still be sufficient to promote plant growth if other conditions were favourable. TP concentrations for Lake Brunner Catchment, to which the Inchbonnie catchment contributes, were compared to TP concentrations that would support the proposed Trophic Level Index. Predictions of the TP concentrations entering Lake Brunner in Scenario Two were below the proposed threshold for the lake. The average measured TP currently in the lake given in Verburg (2009) is already under the proposed TP level. This indicates that the introduction of the TP benchmark to the entire Lake Brunner catchment would guarantee the current TP levels in the lake were maintained.

Two main assumptions were used in this research that may have an impact on whether or not the benchmarks would improve water quality in the catchments. The values used in the water quality modelling assumed that every dairy farmer in the catchment would successfully achieve the benchmark on their farm. The improvement in water quality predicted in this research could be considered a best case scenario because of this assumption. The qualitative interviews showed that the farmers were positive about the need for the benchmarks. However, there were other influencing factors and one could not assume they would all achieve them based on the interview results. Future research will need to determine if this is a realistic assumption.

The second assumption is that while the absolute value of nutrients at a particular location predicted by CLUES may not be accurate the relative change between Scenario One-current water quality prediction, and Scenario Two-benchmark water quality predictions are realistic (Elliott et al., 2011; Lilburne et al., 2011; Monaghan et al., 2010). This may be a limitation to the study. It is difficult to prove this assumption, partially because the equations used to calculate the yields are unknown. The equations are discussed further in the next section. If the relative change is over or underestimated then the prediction that the benchmarks will adequately improve water quality may not be correct. Further research on improving modelling accuracy and determining uncertainties is warranted.

6.3.2 Limitations of the water quality modelling methods

This research took the approach of modifying the current generated yield from Scenario One to meet a specific benchmarked yield. This method of modelling the effect of catchment benchmarks has some limitations. The base spatial unit in CLUES is the REC defined sub-catchment which is one such limitation. Nutrient yield generated from each sub catchment is determined with respect to the proportion of land within the sub-catchment that is designated to each land use, not on a farm by farm basis. The sub-catchment illustrated in Figure 6.1 has 25% of the land used for sheep and beef and the remaining 75% dairy. When the nutrient yield is calculated for this sub-catchment 25% of the total nutrient loss will be determined from the average yield for sheep and beef land use while the remaining 75% will be determined from the average yield for dairy. This is appropriate for sub-catchment scale modelling but does introduce a limitation for introducing farm scale benchmarks.

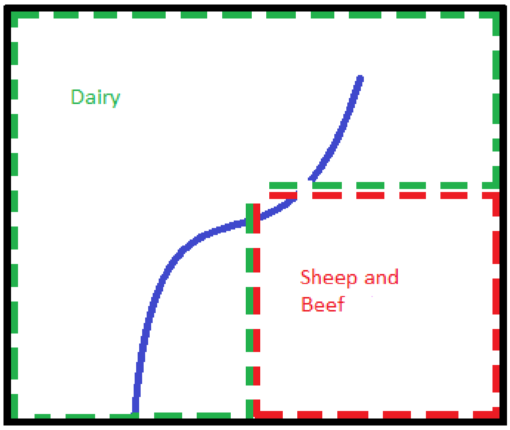

Figure 6.1. An example sub-catchment which has 25% sheep and beef land use and 75% dairy

In order to introduce the benchmark in Scenario two the generated yield for Scenario one was extracted from the attribute table in CLUES. The percentage change required to modify the current generated yield to the benchmark target was calculated and imported into CLUES. The user cannot determine what amount of the generated yield can be attributed to each portion of land use in a sub-catchment. This is not an issue in the Inchbonnie catchment which is 100% dairy as the generated yield for each sub catchment is also 100% from dairy land use. In other catchments, such as the Waikakahi which has mixed land use, it has the potential to be an issue. It is possible that the generated yield for the sub catchment may be over the benchmark but dairy land use may contribute less than the benchmark worth of the generated yield. Alternatively generated yield for the sub catchment may be under the benchmark but dairy land use contribution may be more than the benchmark. Knowledge of the equations used to calculate yields in CLUES as well as the weighting specific land uses are given will be beneficial to future research using this method.

6.3.3 Limitations of the CLUES model

The lack of a groundwater model is a limitation of CLUES. It was particularly noticeable in the Inchbonnie catchment through the predicted and measured flow disagreement. Parshotam and Elliott (2009) suggest the over prediction of flow indicates there may be a significant groundwater influence in the Inchbonnie catchment. Lilburne et al. (2011) noted that in a lot of the Canterbury region it is expected that there are exchanges of N with the groundwater. It is therefore likely that it had some impact on the predictions of TN yield and load in the Waikakahi catchment as well. CLUES cannot currently deal with these surface-groundwater interactions. It assumes groundwater will appear in the overlying surface water catchment. This assumption may be more valid in the large scale catchments that CLUES is calibrated for than the hydrology of the smaller Inchbonnie catchment. The limitation of having no groundwater model is acknowledged in the majority of the literature about CLUES (Elliott et al., 2011; Lilburne et al., 2011; Parshotam & Elliott, 2009; Woods et al., 2004). It is definitely an area for improvement, but it is also dependant on further research to increase understanding of groundwater flow systems in New Zealand.

CLUES has been applied to a variety of situations and has been continuously improved through the identification of weaknesses or needs that arise during these applications (Elliott et al., 2011). CLUES is an empirical model; this means that the results are based on mathematical functions which describe observations of variable behaviour and interactions. No physical laws or processes are taken into consideration. As with other empirical models, CLUES is good at predicting results but involves very simplistic explanations of why these results have arisen (Wainwright & Mulligan, 2004). During the course of this research attempts were made to acquire the specific equations programmed into the CLUES model. This was unsuccessful; Dr Sandy Elliott a catchment modeller at NIWA, explained that as the model has evolved through several different versions, a record of the equations used and changes to them has not been accumulated and kept (S. Elliott, personal communication, December 15, 2011). As a result the inner workings of the model still exist in a black box, despite the accompanying comprehensive user manual. This is a limitation of the CLUES model. When results or outputs do not make sense or are not as expected it is difficult to determine why this has occurred. Explanations as to why may be based on speculation. It makes it difficult to determine what impact adjusting inputs such as stocking rate and land use has in different regions without performing basic sensitivity tests before implementation.

An additional dairy term for TP is supposed to be included in CLUES 3.1 (Elliott et al., 2011; Parshotam & Elliott, 2009). TP and flow predictions from Scenario One for the Inchbonnie catchment were underestimated and do not agree with the measured results from Wilcock et al (2007). They also do not agree with Parshotam and Elliott (2009) predictions from an earlier CLUES model (version

2.0.6) which included an additional dairy term for P loss. The additional dairy term compensates for P losses from sources which are not already included in CLUES such as farm dairy effluent discharges onto land or directly into water or bank erosion. These sources all exist in the Inchbonnie catchment making the additional P term an important feature. When comparing the results for TP load using CLUES version 3.1 (1.62 t/yr) to the results by Parshotam and Elliott (2009) with the additional P term was included (3.70 t/yr) the large differences suggest that the P-term may not be included in CLUES 3.1 or there are other changes to this version that are not apparent. These loads are illustrated in Table 5.3 and Table 5.4.

It is likely that the calibration of the CLUES model also contributes to the underestimation of TP in the Inchbonnie catchment. The catchment hydrology data and water quality predictions from CLUES are calibrated to sites in the New Zealand National Rivers Water Quality Network (NRWQN) (Semadeni-Davies et al., 2011). NRWQN is a long term program established in 1989 that monitors 77 sites on 35 major rivers in New Zealand (Elliott et al., 2005; NIWA, 2012). The NRWQN river catchments are significantly larger than the Inchbonnie catchment. There is uncertainty around attenuation and source terms in these smaller catchments with areas less than 20km^2 (Elliott et al., 2005). This is likely to make calibration to the Inchbonnie catchment less accurate than the calibration to other larger catchments and may influence predicted flows which would further exacerbate errors in TP prediction.

It is important to note that all models use assumptions in order to make predictions. Scientific observations are closer to reality and models are not an adequate substitute for observation if it is possible (Fenton, 2009; Wainwright & Mulligan, 2004). In the long term, as mitigation measures are implemented in the catchments, baseline measurements and measurements after the mitigations could be used to further calibrate the model reducing some of its limitations and improving its capabilities in the future.

6.4 Linkages between the results of the qualitative and quantitative methods

This research employed both qualitative and quantitative methods to determine if the introduction of nutrient benchmarks will achieve sustainable milk production systems. Several important issues that have qualitative and quantitative connections arose during this research. These are: the limitations of the current plan to introduce nationwide benchmarks based on benchmarks developed for the BPDCs, the importance of water quality targets to the benchmarking project and the decision to only introduce a benchmark for one nutrient per catchment. These issues are discussed in this section along with their potential impact on the success of the benchmark project.

The Inchbonnie and Waikakahi catchments have distinctly different social and physical features. DairyNZ originally thought that nutrient benchmarks could be developed nationwide by first piloting development in these two contrasting catchments and adjusting them to fit other catchments or regions. It is apparent in the results of the farmer interviews and water quality modelling that the impact of the social and physical, or qualitative and quantitative, features means this will not be possible.

While the absolute benchmarks from the BPDCs are not practically transferrable, the process by which they have been developed could be. This process is comprised of two parts. Firstly farm scale modelling of both the current nutrient flows on individual farms before and after implementation of potential nutrient loss mitigations. Secondly it involves discussions around the results of the modelling to decide on a benchmark that farmers and stakeholders believe to be achievable and appropriate. The farm scale modelling part of the process has been used to develop a proposed reduction in P loss benchmark for the Inchbonnie catchment. As stated in Chapter 3 the farmers have not yet had an opportunity to discuss the proposed benchmark number.

A similar process has been started in the Waikakahi catchment but a benchmark has not yet been proposed from the farm scale modelling assessments. However, it has indicated that the provisional N benchmark that was modelled for the Waikakahi catchment of 24 kgN/ha/yr is not a realistic target. It was derived from the 25th percentile of N leaching for the entire Canterbury region. Many of the

Waikakahi farms have N losses which are significantly higher than this value. There are variables that influence this N loss, particularly soil type, over which farmers have little control. Further research is needed into a more appropriate benchmark for the region which takes this variability into consideration. An achievable average reduction in N loss per farm, like the type used in the Inchbonnie catchment, is one possible solution.

The shortage of water quality standards set in regional plans in New Zealand is a topic that has emerged throughout this research. The introductory chapters discussed the difficulties faced when setting water quality targets as specific rules under the RMA. They also looked at industry initiatives which have helped to implement better nutrient management practices on farm but also have not set water quality targets in dairying catchments. Nutrient benchmarks are promoted by DairyNZ as a measure that is more useful to farmers than water quality targets. They provide a meaningful target for farmers to quantify their farms nutrient management practice against whereas water quality targets are not meaningful on a farm scale. Five out of the eleven farmers interviewed were of the opinion that the current guidelines are vague or that there is a need for a defined target. Having no water quality targets in the catchments was a limitation to this research and a potential hindrance to the benchmark project.

Water quality targets were needed in order to determine the significance of the water quality improvements in the CLUES predictions. In the absence of regulatory targets the results were compared to other guidelines. While these guidelines are scientifically based and appropriate, they are not known regulations that require compliance, therefore they are unlikely to hold much credence with the farmers. Interview results and meeting observations in this research indicate that farmers from both catchments would like to see quantified justification of the benchmarks as well as some proof of performance. This could be achieved through the development of scientifically robust water quality targets with clear linkages to outcomes sought by the community that were set at an appropriate scale and with consideration of local conditions and values. The gap between current water quality and a target would demonstrate the environmental need for benchmarks. Demonstrating to farmers the beneficial impact of the benchmark on water quality improvements, and achievement of water quality targets will contribute to uptake of benchmarks. Without water quality targets it is likely that it will be difficult to encourage farmers to achieve the benchmarks.

This research highlights the need to have defined targets and the dairy industry considers nutrient benchmarks to be an appropriate target. This pilot benchmark project however, only includes an N loss benchmark for the Waikakahi catchment and a P loss benchmark for the Inchbonnie catchment. The other nutrients are not being specifically addressed through this project. As described in Chapter 2 it is the relationship between N and P that determines whether one or both are the main drivers in plant growth. Investigation into the impact of N in the Inchbonnie catchment and P in the Waikakahi catchment was outside the scope of this research, although there is monitoring information and trends available through the BPDC project reports. Future research into the benchmarking project should consider setting benchmarks for these nutrients as well as investigating whether farmers are willing to achieve them. It may be the case that the benchmarks are set at the current level of loss which will require no changes but will maintain current water quality and provide a quantifiable target in the catchment.

The DairyNZ benchmarking project is not solely focused on quantitative water quality science. It also has large qualitative influences both from the dairy farmers and the wider catchment communities which have been discussed. Farmers in the catchments reflect the attitude that one nutrient is of more concern than the other. In the interviews Waikakahi farmers tended to answer with an emphasis on N loss while Inchbonnie farmers answered with an emphasis on P loss. The dairy industry does realise the importance of managing both nutrients. However, the benchmarks are at present voluntary. Mitigation strategies for the reduction of the two nutrients can be very different, for example managing soils at optimum Olsen P levels reduces P loss but has no effect on N loss. Therefore getting farmers to focus on the nutrient that has the greatest environmental problems is the most pragmatic approach. Focusing on P loss in the Inchbonnie and N loss in the Waikakahi will achieve the environmental and community aims within the catchments while allowing farmers to maintain productive businesses. This is a sustainable dairy production system as defined in Chapter 3.

Chapter 7 Conclusions

The aim of this research was to determine whether nutrient benchmarks will achieve sustainable milk production systems. A mixed methodology was used to investigate this in two contrasting Best Practice Dairy Catchments: Inchbonnie on the West Coast and Waikakahi in South Canterbury.

Three main research questions were posed to achieve this aim:

- What is meant by sustainable milk production systems?
- How do dairy farmers in the two Best Practice Dairy Catchments interpret the benchmarks?
- How effective are benchmarks in managing nutrient loss and improving water quality in the two Best Practice Dairy Catchments?

The main conclusion of this research is that the nutrient benchmarks do have the potential to contribute to the achievement of sustainable milk production systems in the two contrasting catchments. However, they do not provide a silver bullet to the nutrient management issues on New Zealand dairy farms. The conclusions to the three research questions posed which helped to establish this main conclusion are discussed in the following section.

7.1 Main conclusions from the three research questions posed

The first research question was posed in order to clarify the meaning of a sustainable milk production system which is referred to in the main research aim. A sustainable milk production system was determined to be a dairy farm that is able to meet three values of the place the system is located in simultaneously. These values are: the current economic (or production) needs of the farmer, the social/cultural values and environmental values. The second and third research questions were answered using qualitative and quantitative research methodologies respectively. The conclusions of these research questions are given in this section with respect to whether they indicate the ability of the benchmarks to achieve sustainable milk production systems.

Question two investigated how the dairy farmers in the two Best Practice Dairy Catchments interpreted the benchmarks. In general the dairy farmers were positive about the usefulness of benchmarks in their catchments. It is apparent that this positive interpretation may be influenced in the future by the three values that a sustainable milk production system is comprised of. Economics, such as increasing profits or production, and environmental concerns, such as not losing nutrients to waterways, emerged as two potential key drivers of benchmark achievement. Further research into the weighting that these two values have to farmers in the individual catchments and which one is more influential is needed to accurately determine the benchmark success. Maintaining the water quality of Lake Brunner was noted by the Inchbonnie farmers as a potential driver to achieving the benchmarks. It is likely that having this additional driver, which incorporates both environmental and social/cultural values will mean the benchmarks are more successful at helping achieve sustainable milk production systems in the Inchbonnie catchment than in the Waikakahi catchment.

Question three explored the effectiveness of the benchmarks in managing nutrient loss and improving water quality in the two Best Practice Dairy Catchments. The introduction of nutrient benchmarks will result in an improvement in water quality in catchments. The significance of this improvement determines if the benchmark will be successful in achieving sustainable milk production systems. A significant improvement is one which enables the catchment water quality to meet set water quality targets. These targets are theoretically developed to meet both environmental and social/cultural values in the catchment, such as trout spawning sites, reduction of nuisance weeds or maintenance of recreational water quality. The process which has been used by DairyNZ to develop the proposed Inchbonnie P loss benchmark also takes cost efficiency on farm, which is an economic value, into consideration. Therefore if the improvement in water quality from the introduction of benchmarks meets set water quality targets they will help achieve successful milk production systems. The implications that the conclusions drawn from these questions as well as the main conclusion will have on the DairyNZ benchmarking project as well as recommendations for the future are presented in the following sections.

7.2 Implications and recommendations for the DairyNZ benchmarking project

The aim of the DairyNZ benchmarking project was to pilot the introduction of benchmarks to two contrasting BPDCs while a national roll-out was developed. The impacts of the contrasting social and physical features of the two catchments on the development of benchmarks instead suggested that benchmarks need to be developed individually for each catchment or region. Benchmarks set for the two BPDCs will not easily be adjusted to fit other catchments. Nonetheless, the process that was used to determine nutrient benchmarks for the BPDCs, which integrated both qualitative and quantitative methodologies, could be applied to other catchments. This conclusion creates the need for changes in the implementation of the benchmarking project nationwide. A potential change could be the creation of a specialist team to carry out farm scale modelling as well as lead benchmark development discussions within dairy farming catchments.

BPDC farmers recognised both the environmental and economic implications of the concept of nutrient benchmarks. It was outside the scope of this research to determine the level of commitment farmers have to the environment. It is recommended that further research focus on this, particularly in relation to the influence economic cost has on their environmental commitment. This is important, particularly if the benchmarks remain voluntary, because ultimately for the benchmarks to succeed farmers have to be committed to implementing them on their farms. Information from the farm scale modelling which has recently been completed in both catchments should be used as the basis of future research. It provides a good indication of the effectiveness and cost of proposed mitigations specific to the catchments which would be required to meet benchmarks on individual farms.

There was an understanding by the farmers that one nutrient was of particular concern in their catchment. In the Waikakahi catchment it was nitrogen and in the Inchbonnie catchment it was phosphorus. Mitigations, such as applying nitrification inhibitors in the Waikakahi catchments and low solubility P fertiliser in the Inchbonnie catchment, would reduce the loss of the respective nutrient. They have been actively promoted by DairyNZ and AgResearch in the catchments through the BPDC project but not well adopted. There is the possibility this is related to the underutilisation of nutrient budgets and nutrient management plans in the catchments. This underutilisation indicates that knowledge of nutrient flows, particularly outputs, on farms may be low. It is suggested that further research should address why the uptake of mitigations is currently low and whether further education around nutrient flows on farms will help improve understanding of why mitigations are warranted.

One limitation to the success of benchmarks achieving sustainable milk production systems is around appropriate regulatory water quality targets that are clearly linked to community values, are realistic and achievable, and are based on robust science. Successful achievement of both water quality targets and benchmarks are related to each other. Water quality targets by themselves are not applicable at a farm scale level. They become relevant to dairy farmers when they are used to ascertain the need for nutrient benchmarks that improve the current water quality to reach the water quality target. The achievement of a benchmark does not guarantee significant water quality improvements have been achieved. The water quality improvements from benchmarks need to be compared to water quality targets to establish if the benchmarks have the potential to achieve environmental aims. Some water quality targets have already been established and it is likely that the new National Policy Statement for Freshwater, which was discussed in Section 2.4.2 Central government management under the RMA, will advance development of water quality targets across the country.

7.3 Recommendations for the CLUES model

The GIS based CLUES water quality prediction model was very important to the quantitative portion of this research. The limitations of the CLUES model are acknowledged in Chapter 6. Several recommendations for the future development of CLUES can be made from these limitations.

CLUES makes predictions for total nutrients (TP and TN). It does not predict the loads or concentrations of dissolved nutrient concentrations such as Dissolved Reactive Phosphorus (DRP) or Nitrate-Nitrite Nitrogen (NNN) which are often the form of nutrient that water quality targets are measured in. The relationship between NNN and TN in the Waikakahi catchment for this research was good but this is not always the case. DRP and TP especially are not well correlated. Further research needs to address these modelling limitations particularly in regard to relating predictions to appropriate water quality targets which are mentioned in the previous section.

Further development of the CLUES model is needed to increase its ability to accurately predict nutrient loads and concentrations. This includes an exploration into the assumption that the relative change between two predicted scenarios is more accurate than the absolute predicted values. As well as the inclusion of a groundwater model to improve predictions in catchments with strong groundwater influences.

References

AgResearch. (2011). *AgResearch Annual Report Financials 2010/2011*. Retrieved from http://www.agresearch.co.nz/publications/annualreport/annual-report-2010-2011/docs/Annual%20Report%202010-2011%20(PDF,%202.29MB).pdf

Agri-food sector to assess its environmental footprint. (2009, May 7). *EurActive* Retrieved from http://www.euractiv.com/en/cap/agri-food-sector-assess-environmental-footprint/article-182083

Another rise in 'dirty dairying' (2011, March 19). *Otago Daily Times*. Retrieved from www.odt.co.nz

Australian and New Zealand Environment and Conservation Council (ANZECC). (2000). *National Water Quality Management Strategy: Australian and New Zealand Guidelines for Fresh and Marine Water Quality.* Canberra, Australia: Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand.

Aqualinc. (2008). *Morven Glenavy Irrigation Efficiency Improvements and Area Expansions-Assessment of Environmental Effects* (Report No. L07113/2). Prepared for Morven Glenavy Ikawai Irrigation Co Ltd. Christchurch, New Zealand: Aqualinc Research Limited.

Ballantine, D., Booker, D., Unwin, M., & Snelder, T. (2010). *Analysis of national river water quality data for the period 1998-2007* (NIWA Client Report: CHC2010-038). Prepared for Ministry for the Environment. Wellington, New Zealand: NIWA

Barnett, J., & Pauling, J. (2005). The Environmental Effects of New Zealand's Free-Market Reforms. *Environment, Development and Sustainability, 7*(2), 271-289.

Bay of Plenty Times. (2011, April 22). Sustainable milk could reach top dollar, *Bay of Plenty Times*. Retrieved from http://www.bayofplentytimes.co.nz

BBC. (2011, May 9). *New Zealand PM John Key: 'We are 100% Pure'* John Key speaks with BBC interviewer Stephen Sackur. Retrieved from http://news.bbc.co.uk

Bewsell, D., & Kaine, G. (2005, March). *Adoption of environmental best practise amongst dairy farmers*. Paper presented at the Practice change for sustainable communities: Exploring footprints, pathways and possibilities: APEN 2006 International Conference.Retrieved from http://www.regional.org.au/au/apen/2006/refereed/4/2873_bewselld.htm?print=1

Bewsell, D., Monaghan, R. M., & Kaine, G. (2007). Adoption of stream fencing among dairy farmers in four New Zealand catchments. *Environmental Management,* 40, 201-209.

Blackett, P., Washington, S., & Nimmo, K. (2005). *Humps and hollows on West Coast dairy farms: farmer management practices and responses to nutrient runoff solutions* (NIWA Client Report: CHC2005-062). Prepared for Sustainable Farming Fund. Christchurch, New Zealand: NIWA

Brace, I. (2008). *Questionnaire Design : How to Plan, Structure and Write Survey Material for Effective Market Research (2nd Edition)*. London, England: Kogan Page Ltd.

Bramley, M. (2009). *Lake Brunner Project Update October 2009*. Retrieved from http://maxa.maf.govt.nz/sff/about-projects/search/06-064/summary-for-farmers.pdf

Briggs, D., & Smithson, P. (1985). *Fundamentals of Physical Geography*. London, England: Hutchinson Education.

Buchan, D., Meister, A., & Giera, N. (2006). *Bridging the gap between environmental knowledge and research, and desired environmental outcomes to achieve sustainable land management*. Prepared for MAF Policy. Wellington, New Zealand: Nimmo-Bell & Company Ltd.

Burns, N., McIntosh, J., & Scholes, P. (2009). Managing the lakes of the Rotorua District, New Zealand. *Lake and Reservoir Management, 25*(3), 284-296.

Cameron, M., & Trenouth, C. (1999). *Resource Management Act- Practice and Performance: Are desired environmental outcomes being achieved at least cost? A case study of farm dairy effluent management.* Wellington, New Zealand: Ministry for the Environment.

Campbell, J., Houlbrooke, D., Wilcock, R., & Monaghan, R. (2010). The influence of land management practices on trends in N and P losses to water from dairy farms in the Waikakahi Catchment. In L. Currie & C. Christensen (Eds.), *Farming's future: Minimising footprints and maximising margins.* Palmerston North, New Zealand: Fertiliser and Lime Research Centre, Massey University.

Carey, P., Drewry, J., Muirhead, R., & Monaghan, R. (2004). *Potential for nutrient and faecal bacteria losses from a dairy pasture under border-dyke irrigation: a case study* (Proceedings of the New Zealand Grassland Association Volume 66). Ashburton, New Zealand: NZ Grassland Association.

Celsias. (2011). *Westland Milk-Moving Ahead on Sustainability*. Retrieved from http://www.celsias.co.nz/article/westland-milk-moving-ahead-sustainability/

Chague-Goff, C., Duncan, M., McDowell, R., & Cotton, S. (2009). *Characterising soil nutrient accumulation and loss from dairy farm pastures on the West Coast: Project 06/064-EN069: Final Year Report- 2007-2009* (NIWA Client Report: CHC2009-151). Prepared for Sustainable Farming Fund and DairyNZ. Christchurch, New Zealand: NIWA.

Chague-Goff, C., Duncan, M., Sorrell, B., & Washington, S. (2006). *Solutions to nutrient runoff from West Coast land conversions 03/126 Final report 2004-2006* (NIWA Client Report: CHC2006-120). Prepared for Sustainable Farming Fund. Christchurch, New Zealand: NIWA.

Chamberlain, B. (2008, April). *Acting to promote a sustainable high quality water resource and dairy industry—a Taranaki perspective*. Paper presented at the Dairy Summit 2008. Retrieved from http://www.trc.govt.nz/assets/taranaki/environment/land/pdfs/dairysummit.pdf

Chan, J. (2010). *Nutrient Management Planning* [DairyNZ discussion paper]. Lincoln, New Zealand: DairyNZ

Chan, J. (2011). *Nutrient Management Plans: A tool to improve Resource Use Efficiency* [DairyNZ discussion paper]. Lincoln, New Zealand: DairyNZ

Clarke, K. (2003). *Getting started with geographic information systems*. New Jersey: Pearson Education.

Close, M., Dann, R., Ball, A., Pirie, R., Savill, M., & Smith, Z. (2008). Microbial groundwater quality and its health implications for a border strip irrigated dairy farm catchment, South Island, New Zealand. *Journal of Water and Health, 6*(1), 83-98.

Conforte, D., Garnevska, E., Kilgour, M., Locke, S., & Scrimgeour, F. (2008). *The key elements of success and failure in the NZ Dairy industry* (Research Report No. 313). Lincoln, New Zealand: Lincoln University, Agribuisiness and Economics Research Unit.

Cope, M. (2005). Coding Qualitative Data. In I. Hay (Ed.), *Qualitative Research Methods in Human Geography* (2nd ed., pp. 223-233). South Melbourne, Australia: Oxford University Press.

Creswell, J. W. (2009). *Research Design: Qualitative, quantitative and mixed method approaches* (3rd ed.). United States of America: Sage Publishing Inc.

Crossman, J. (2009). *Waikakahi Stream* (Unpublished Report). Christchurch, New Zealand: Environment Canterbury.

Cullen, R., Hughey, K., & Kerr, G. (2006). New Zealand freshwater management and agricultural impacts. *The Australian Journal of Agriculture and Resource Economics, 50*, 327-346.

Dairy Australia. (2008). Nutrient Budgeting *Effluent and Manure Management Database for the Australian Dairy Industry* (pp. 95-103). Victoria, Australia; Dairy Australia.

DairyNZ. (2009a). *About DairyNZ.* Retrieved from http://www.dairynz.co.nz/.

DairyNZ. (2009b). *Strategy for New Zealand Dairy Farming 2009/2020*. Retrieved from DairyNZ website: http://www.dairynz.co.nz/file/fileid/28814.

DairyNZ. (2010a). *Dairy Industry Strategy: Direction to the vision*. Retrieved from DairyNZ website: http://www.dairynz.co.nz/file/fileid/33362

DairyNZ. (2011a). *DairyNZ Annual Report 2011*. Retrieved from http://www.dairynz.co.nz/file/ fileid/39528

DairyNZ. (2011b). *Nutrient benchmark proposals*. [DairyNZ discussion paper]. Lincoln, New Zealand: DairyNZ.

DairyNZ. (2011, April). Nutrient losses 'one of our greatest challenges'. *Inside Dairy, April 2011,* 6-7. Retrieved from DairyNZ, Inside Dairy database

DairyNZ, & Livestock Improvement Corporation. (2011). *New Zealand Dairy Statistics 2010-11*. Retrieved from Livestock Improvement Corporation, Publications website: http://www.lic.co.nz/pdf/DAIRY%20STATISTICS%2010-11-WEB.pdf

DCANZ. (2011). *About DCANZ.* Retrieved from http://www.dcanz.com/about-dcanz

Deans, N., & Hackwell, K. (2008). *Dairying and Declining Water Quality. Why has the Dairying and Clean Streams Accord not delivered cleaner streams?*Retrieved from Forest and Bird website: http://www.forestandbird.org.nz/files/file/Dairying_and_Declining_Water_Quality(2).pdf

DeMers, M. (1997). *Fundamentals of Geographic Information Systems*. New York: John Wiley & Sons.

Edgar, N. (2008). Icon lakes in New Zealand: Managing the Tension Between Land Development and Water Resource Protection. *Society and Natural Resources, 22*(1), 1-11.

Edwards, C., & DeHaven, T. (2002, March 3). Save the Farms - End the Subsidies, *Washington Post*. Retrieved from http://www.washingtonpost.com

Elliott, A., Alexander, R., Schwarz, G., Shankar, U., Sukias, J., & McBride, G. (2005). Estimation of nutrient sources and transport for New Zealand using the hybrid mechanistic-statistical model SPARROW. *Journal of Hydrology (New Zealand), 44*(1), 1-27.

Elliott, S., Semadeni-Davies, A., & Shankar, U. (2011). *CLUES Catchment Modelling-Lessons from recent applications*. In L. Currie & C. Christensen (Eds.), *Adding to the knowledge base for the nutrient manager* (Occasional Report No. 24). Palmerston North, New Zealand: Fertiliser and Lime Research Centre, Massey University.

Environment Bay of Plenty. (2008). *Operative Regional Water and Land Plan.* Retrieved from Environment Bay of Plenty website: http://www.boprc.govt.nz/knowledge-centre/plans/regional-water-and-land-plan

Environment Bay of Plenty. (2011, February 21). *Algae treatment for Lake Rotoiti* [Press Release]. Retrieved from http://www.boprc.govt.nz/news-centre/media-releases/february-2011/algae-treatment-for-lake-rotoiti/

Environment Bay of Plenty. (n.d.). *Lake Rotorua Base Map* [Base Map]. Retrieved from http://www.boprc.govt.nz/media/43836/c2219_lakerotoruabase.pdf

Environment Canterbury. (2009a, February 11). *Dog dies after licking algal mats on Ashley River/Rakahuri* [Press Release]. Retrieved from http://ecan.govt.nz/news-and-notices/news/Pages/dog-dies-after-licking-algal-mats-ashley-river-rakahuri.aspx

Environment Canterbury. (2009b, February 17). *Lake Ellesmere/ Te Waihora health warning blue-green algal bloom* [Press Release]. Retrieved from http://ecan.govt.nz/news-and-notices/news/Pages/lake-ellesmere-te-waihora-health-warning-blue-green-algal-bloom.aspx

Environment Canterbury. (2010a). *Canterbury Natural Resources Regional Plan Chapter Four Water Quality*. Retrieved from Environment Canterbury website: http://ecan.govt.nz/publications/Pages/chapter-4-nrrp.aspx

Environment Canterbury (2010b). *Decision of the Hearing Committee in the matter of Resource consent applications by Morven Glenavy Ikawai Irrigation company Ltd* (Consent No. C10c-7436). Christchurch, New Zealand: Environment Canterbury

Environment Waikato (2000). *Operative Waikato Regional Policy Statement.* Retrieved from Environment Waikato website: http://www.waikatoregion.govt.nz/Council/Policy-and-plans/Regional-Policy-Statement/Operative-Waikato-Regional-Policy-Statement-October-2000/

Environment Waikato. (2011a). *Algal Blooms in the Waikato region.* Retrieved from http://www.waikatoregion.govt.nz/

Environment Waikato. (2011b). *Managing Farm Runoff*. Retrieved from http://www.waikatoregion.govt.nz/

Environment Waikato. (2011c). *Waikato Regional Plan.* Retrieved from Environment Waikato website: http://www.waikatoregion.govt.nz/Council/Policy-and-plans/Rules-and-regulation/Regional-Plan/Waikato-Regional-Plan/

Environment Waikato. (n.d.). *Lake Taupo Catchment.* Retrieved from http://www.waikatoregion.govt.nz/

Environmental Defense Society. (unknown). *Resource Management Act for the community.* Retrieved from http://www.rmaguide.org.nz/index.cfm

Espinoza, L., Norman, R., Slaton, N., & Daniels, M. (2005). *The nitrogen and phosphorus cycle in soils*. Retrieved from University of Arkansas, Division of Agriculture website: http://www.uaex.edu/Other_Areas/publications/PDF/FSA-2148.pdf

ESRI. (2009). *ArcGIS Desktop 9.3 Help* Retrieved from http://webhelp.esri.com/

Fenton, T. (2009, July). *Overview of Catchment Scale Nutrient Modelling in New Zealand.* Paper presented at the Envirolink: Catchment Scale Modelling. Retrieved from http://www.irap.org.nz/publications.php

Fergusson, R. (1987). Accuracy and precision of methods for estimating river loads. *Earth surface processes and landforms, 12*, 95-104.

Fink, A., Frey, J., & Oishi, S. (1995). *The survey kit*. California: Sage Publications.

Fish & Game. (2009, March 12). *Clean Streams Accord Stalled* [Press Release]. Retrieved from http://www.scoop.co.nz/stories/PO0903/S00132.htm

Fish & Game New Zealand. (2012a). *About Fish & Game*. Retrieved from http://www.fishandgame.org.nz/

Fish & Game New Zealand. (2012b). *Fish & Game Structure.* Retrieved from http://www.fishandgame.org.nz/

Fonterra (2003). *Dairying and Clean Streams Accord.* Retrieved from Ministry for the Environment website: http://www.mfe.govt.nz/issues/land/rural/dairying-accord-may03.pdf

Fonterra. (2007). *The Dairying and Clean Streams Accord: Snapshot of Progress – 2006/2007*. Retrieved from Ministry for the Environment website: http://www.mfe.govt.nz/publications/land/dairying-clean-streams-accord-snapshot-feb08/index.html

Fonterra. (2010a, August 5). *Fonterra Launches Programme to Tackle Effluent Issues* [Press Release]. Retrieved from http://www.fonterra.com/wps/wcm/connect/fonterracom/fonterra.com/our+business/news/media+releases/fonterra+launches+programme+to+tackle+effluent+issues

Fonterra. (2010b). *The natural source of dairy nutrition: Fonterra Annual Report 2010*. Auckland, New Zealand: Fonterra

Fonterra. (2011a). *The Dairying and Clean Streams Accord: Snapshot of progress*. Retrieved from Ministry of Agriculture website: http://www.maf.govt.nz/news-resources/publications.aspx?title=Dairying%20and%20Clean%20Streams%20Accord:%20Snapshot%20of%20Progress

Fonterra. (2011b). *Fonterra Annual Review 2011*. Retrieved from http://www.fonterra.com/wps/wcm/connect/fc7cd500487dc02484288458a9b11389/Annual+Review+web.pdf?MOD=AJPERES&CACHEID=fc7cd500487dc02484288458a9b11389

Fonterra. (2011c). *Our History* Retrieved from http://www.fonterra.com/

GeoNet. (n.d.). *Taupo* Retrieved from http://www.geonet.org.nz

Gibb, M., & Bennett, A. (2007, August). Maori claims to ownership of freshwater. *Resource Management Journal*. 13-18. Retrieved from Resource Management Law Association of New Zealand Inc. Database: http://www.rmla.org.nz/upload/files/2007_aug_rmla.pdf

Gray, S., & Le Heron, R. (2010). Globalising New Zealand: Fonterra Co-operative Group, and shaping the future. *New Zealand Geographer, 66*, 1-13.

Hamilton, B. (2003). *A review of short-term management options for Lakes Rotorua and Rotoiti*. A report prepared for the Ministry for the Environment. Wellington, New Zealand: Hamilton Integrated Management.

Harper, D. (1992). *Eutrophication of Freshwaters: Principles, problems and restoration*. Suffolk, England: Chapman and Hall.

Hauser, J. (2010, July). On the causes of milk price volatility. *Australian Dairyfarmer*.

Hayward, S. (2010). *Best Practice Dairying Catchments: Summary of project history, gains in understanding and future of the project*. [DairyNZ discussion paper]. Lincoln, New Zealand: DairyNZ

Hesse-Biber, S. N., & Leavy, P. (2006). *The Practice of Qualitative Research*. California: Sage Publications.

Hickey, C., & Martin, M. (2009). *A review of nitrate toxicity to freshwater aquatic species*. (Report No. R09/57). Christchurch, New Zealand: Environment Canterbury

Hopkins, C. (1976). Estimate of biological production of some stream invertebrates. *New Zealand Journal of Marine and Freshwater Research, 10*, 629-640.

Horrox, J. (2008). *West Coast Surface Water Quality* (State of the Environment Technical Report 08002). Greymouth, New Zealand: West Coast Regional Council.

Horrox, J., Chaney, E., & Beel, C. (2011). *West Coast Surface Water Quality* (State of the Environment Technical Report 11001). Greymouth, New Zealand: West Coast Regional Council.

Houlbrooke, D., Horne, D., Hedley, M., Hanly, J., & Snow, V. (2004). A review of literature on the land treatment of farm-dairy effluent in New Zealand and its impact on water quality. *New Zealand Journal of Agricultural Research, 47*, 499-511.

Hughey, K., Kerr, G., & Cullen, R. (2004). *Public Perceptions of New Zealands Environment: 2004.*Retrieved from Lincoln University, Agribuisness and Economics Research Unit (AERU) website: http://researcharchive.lincoln.ac.nz/dspace/handle/10182/857

Hughey, K., Kerr, G., & Cullen, R. (2010). *Public Perceptions of New Zealand's Environment: 2010*. Retrieved from Lincoln University, Agribuisness and Economics Research Unit (AERU) website: http://researcharchive.lincoln.ac.nz/dspace/bitstream/10182/3875/1/Perceptions_2010.pdf

Human Rights Commision. (2009). *Te Arawa-Rotorua Lakes Restoration Program*. Retrieved from http://www.hrc.co.nz/

Hutchings, J. (2010). *Sustainable management is important for Fonterra's trading opportunities and New Zealand*. Paper presented at the 23rd Annual Fertiliser and Lime Research Center Workshop held at Massey University, Palmerston North, New Zealand. Abstract retrieved from http://www.massey.ac.nz/~flrc/workshops/10/Abstracts%202010.pdf

Iarossi, G. (2006). *Power of Survey Design : A User's Guide for Managing Surveys, Interpreting Results, and Influencing Respondents*. Hemdon, Virginia: World Bank Publications.

International Dairy Federation. (n.d.). *Welcome to the IDF website* Retrieved from http://www.fil-idf.org/

Jessen, M., & Harcombe, M. (2008). *Peer Review: DAIRY AND DECLINING WATER QUALITY Why has the Dairying and Clean Streams Accord not delivered cleaner streams?* Wellington, New Zealand: Federated Farmers.

Jongeneel, R., van Berkum, S., de Bont, C., van Bruchem, C., Helming, J., & Jager, J. (2010). *European dairy policy in the years to come; Quota abolition and competitiveness* (LEI Report 2010-017). The Hague, The Netherlands: LEI Wageningen UR.

Joy, M. (2011, April 25). The dying myth of a clean, green Aotearoa, *The New Zealand Herald*. Retrieved from http://www.nzherald.co.nz

Kelly, D., & Norton, N. (2010). *Current nutrient loads and options for nutrient load limits for a case study catchment: Hurunui catchment* (Report No. R10/66). Christchurch, New Zealand: Environment Canterbury.

Kilsby, S. (2010). *Special report: Dealing with Volatility in Dairy Markets*. Retrieved from Agrifax website: http://www.nzxfutures.com/system/downloads/19/Dealing%20with%20Volatility %20in%20Dairy%20Markets%20.pdf?1295905935

Lake Taupo Protection Trust. (n.d.). *Trust Funding* Retrieved, from http://www.laketaupoprotectiontrust.org.nz/

Lakes Management Strategy Working Group. (2000). *Strategy for the lakes of the Rotorua district* Rotorua, New Zealand: Lakes Management Strategy Working Group.

Land and Water Forum. (2010). *Report of the Land and Water Forum a Fresh Start for Fresh Water*. New Zealand: Land and Water Forum.

Laurenson, S., McDowell, R., Power, I., & Dennis, S. (2012). *Phosphorus benchmark development for Lake Brunner.* Report prepared for DairyNZ Limited. Mosgiel, New Zealand: AgResearch.

Ledgard, S., Crush, J., & Penno, J. (1998). Environmental Impacts of different nitrogen inputs on dairy farms and implications for the Resource Management Act of New Zealand. *Environmental Pollution, 102*(1), 515-519.

Lilburne, L., Elliott, S., Bidwell, V., Shankar, U., Kelly, D., & Hanson, C. (2011). *Hurunui catchment-scale land use and water quality modelling report* (Report No. R11/15). Christchurch, New Zealand: Environment Canterbury.

Mackay, M., & Smith, E. (2010). *Best Practice Dairying Catchments: Farmer Environmental Outlook Survey - 2010.* Report prepared for DairyNZ. Christchurch, New Zealand: AgResearch.

MAF FertResearch and AgResearch. (2010). *OVERSEER model*. Retrieved from http://www.overseer.org.nz/

McChesney, I. (1991). *The Brundtland Report and sustainable development in New Zealand* (Information Paper No. 5). Christchurch, New Zealand:Lincoln University and University of Canterbury, Centre for Resource Management.

McCrone, J. (2011, September 10). Who controls our water?, *Waikato Times*. p. B6.

McDowell, R. (2008). Phosphorus in humped and hollowed soils of the Inchbonnie catchment West Coast, New Zealand: I. Variation with age and distribution. *New Zealand Journal of Agricultural Research, 51*(3), 299-306.

McDowell, R. (2010). Evaluation of two management options to improve the water quality of Lake Brunner, New Zealand. *New Zealand Journal of Agricultural Research, 53*(1), 59-69.

McDowell, R., Larnard, S., & Houlbrooke, D. (2009). Nitrogen and Phosphorus in New Zealand streams and rivers: control and impact of eutrophication and hte influence of land management. *New Zealand Journal of Marine and Freshwater Research, 43*, 985-995.

McGuirk, P., & O'Neill, P. (2005). Using Questionnaires in Qualitative Human Geography. In I. Hay (Ed.), *Qualitative Research Methods in Human Geography* (2nd ed., pp. 191-216). Melbourne, Australia: Oxford University Press.

Memon, P. A. (1997). Freshwater management policies in New Zealand. *Aquatic Conservation: Marine and Freshwater Ecosystems, 7*(4), 305-322.

Meredith, A., Smith, Z., & Lavender, R. (2003). *Waikakahi Stream: assessment of water quality and ecosystem monitoring, 1995 to 2002 (*Report No. R03/14). Christchurch, New Zealand: Environment Canterbury.

Milne, P. (2008). *When is enough, enough? Dealing with cumulative effects under the Resource Management Act.* Retrieved from Quality Planning website: http://www.qualityplanning.org.nz/pubs/Dealing-with-cumulative-effect-under-the-RMA.pdf

Ministry for the Environment. (2009). *Water Quality in Selected Dairy Farming Catchments. A baseline to support future water-quality trend assessment* (Publication number: ME 944). Wellington, New Zealand: Ministry for the Environment.

Ministry for the Environment. (2011a). *Dairying*. Retrieved from http://www.mfe.govt.nz/

Ministry for the Environment. (2011b). *National Policy Statement for Freshwater Management*. Retrieved from Ministry for the Environment Website: http://www.mfe.govt.nz/rma/central/nps/freshwater-management.html

Ministry of Agriculture and Forestry. (2011*). Sustainable Farming Fund.* Retrieved from http://www.maf.govt.nz/

Ministry of Health. (2005). *Draft Guidelines for Drinking-water Quality Management for New Zealand*. Retrieved from Ministry of Health website: http://www.health.govt.nz/publication/ guidelines-drinking-water-quality-management-new-zealand

Monaghan, R., Carey, P., Wilcock, R., Drewry, J., Houlbrooke, D., Quinn, J., et al. (2009a). Linkages between land management activities and stream water quality in a border-dyke irrigated pastoral catchment. *Agriculture, Ecosystems and Environment, 129*, 201-211.

Monaghan, R., de Klein, C., & Muirhead, R. (2008). Prioritisation of farm scale remediation efforts for reducing losses of nutrients and faecal indicator organisms to waterways: a case study of New Zealand dairy farming. *Journal of Environmental Management, 87*, 609-622.

Monaghan, R., Hedley, M., Di, H., McDowell, R., Cameron, K., & Ledgard, S. (2007a). Nutrient management in New Zealand pastures-recent develpment and future issues. *New Zealand Journal of Agricultural Research, 50*(2), 181-201.

Monaghan, R., Rutherford, A., McDowell, R., & Smith, C. (2007b). *Linkages between land management practices and potential impacts on soil and water quality within the Inchbonnie catchment.* Summary report prepared for the Inchbonnie Catchment Group. Mosgiel, New Zealand: AgResearch.

Monaghan, R., Semadeni-Davies, A., Muirhead, R. W., Elliott, S., & Shankar, U. (2010). *Land Use and Land Management Risks to Water Quality in Southland*. Report prepared for Environment Southland. Mosgiel, New Zealand: AgResearch.

Monaghan, R., Wilcock, R. J., Smith, C., Houlbrooke, D., McGowan, A., Quinn, J., et al. (2009b). *Best Practice Dairy Catchments Study*. Summary Report to SFF. Mosgiel, New Zealand: AgResearch.

New Zealand Dairy Industry. (2011). *History*. Retrieved from http://www.dcanz.com/

New Zealand Fertiliser Manufacturer Research Association. (2007). *Code of Practice for Nutrient Management*. Retrieved from Fert Research website: http://www.fertresearch.org.nz/code-of-practice

New Zealand Fertiliser Manufacturer Research Association. (2009, March). External auditing of nutrient budgets adds integrity to practice. *Fertiliser Matters*, 40, p.1. Retrieved from

FertResearch Fertiliser Matters database: http://www.fertresearch.org.nz/resource-centre/newsletter-fertiliser-matters

NIWA. (2012). *National River Water Quality Network (NRWQN)* Retrieved from http://www.niwa.co.nz/

NZFishing. (n.d.). *Lake Brunner Map*. Retrieved from www.nzfishing.com

O'Connor, M., Boddy, I., Morton, J., & Edmeades, D. (1996). Nutrient budgets-a key indicator of soil sustainability. *Proceedings of the New Zealand Grassland Association* (58), 219-222.

O'Keefe, P. (2010, December 4). Southland - a lesson for Ireland. *Irish Farmers Journal*. Retrieved from http://www.farmersjournal.ie/site/farming-Southland-a-lesson-for-Ireland-12112.html

OECD. (2007). *OECD Environmental Performance Review of New Zealand*. Paris, France: Organisation for Economic Cooperation and Development

Office of the Minister for the Environment. (2009). *New Start for Fresh Water*. Retrieved from Ministry for the Environment website: http://www.mfe.govt.nz/issues/water/freshwater/new-start-fresh-water.html

Parffit, J. (2005). Questionnaire design and sampling. In R. Flowerdew & D. Martin (Eds.), *Methods in Human Geography: A guide for students doing a research project* (pp. 78-106). England: Prentice Hall.

Parliamentary Commissioner for the Environment. (2004). *Growing for Good Intensive farming, sustainability and New Zealand's environment*. Retrieved from the Parliamentart Commissioner for the Environment website: http://www.pce.parliament.nz/publications/all-publications/growing-for-good-intensive-farming-sustainability-and-new-zealand-s-environment-3

Parliamentary Commissioner for the Environment. (2006). *Restoring the Rotorua Lakes: The ultimate endurance challenge*. . Retrieved from the Parliamentart Commissioner for the Environment website: http://www.pce.parliament.nz/publications/all-publications/restoring-the-rotorua-lakes-the-ultimate-endurance-challenge

Parshotam, A., & Elliott, S. (2009). *Application of CLUES to Five Monitored Dairy Catchments in New Zealand* (NIWA Client Report: HAM2009-132). Prepared for AgResearch. Hamilton, New Zealand: NIWA

Pearce, F. (2009, November 12). New Zealand was a friend to Middle Earth, but it's no friend of the earth. *The Guardian*. Retrieved from www.guardian.co.uk

Petch, T., Young, J., Thorrold, B., & Vant, B. (2003). *Protecting an icon managing sources of diffuse nutrient inflow to Lake Taupo, New Zealand*. Paper presented at the Diffuse Pollution and Basin Management 7th International Specialised IWA Conference, Dublin, Ireland. Retrieved from http://www.ucd.ie/dipcon/docs/theme01/theme01_10.PDF

Piddock, G. (2011, February 24). Warning to dairy farmers, *Otago Daily Times*. Retrieved from www.odt.co.nz

Resource Management Act 1991, No. 69 (as at 01 October 2011).

Retailers, food industry in sustainability pledge . (2009, March 3). *EurActive*. Retrieved from http://www.euractiv.com/sustainability/retailers-food-industry-sustainability-pledge/article-179878

Rotorua Lakes Strategy Group. (2007). *Proposed Lakes Rotorua & Rotoiti Action Plan: A programme for the long-term restoration of Lakes Rotorua and Rotoiti's water quality* (Environmental Publication 2001/11). Retrieved from Environment Bay of Plenty website: http://old.boprc.govt.nz/Plans/Plan-070700-ProposedLakesRotoruaAndRotoitiActionPlan.pdf

Royal, T. (Ed.). (2003). *The woven universe: selected writings of Rev Maori Marsden*. New Zealand: Mauriora-ki-te-ao.

Russell, J. M. (2003). *Final Report on the Best Practice Dairy Catchments Project* (SFF Project No 00/145). Retrieved from Ministry of Agriculture and Forestry website: http://maxa.maf.govt.nz/sff/about-projects/search/00-145/00-145-final-report.pdf

Russell, J. M., Monaghan, R., Wilcock, R., & Bramley, M. (2006). *Final Report on the Best Practice Dairy Catchments Project* (SFF Project No 03/069). Retrieved from Ministry of Agriculture and Forestry website: http://maxa.maf.govt.nz/sff/about-projects/search/03-069/03-069final-report.htm

Rutherford, A., Chague-Goff, C., & McKerchar, A. (2008). *Nutrient load estimates for Lake Brunner.* (NIWA Client Report: HAM2008-060) Prepared for West Coast Regional Council. Hamilton, New Zealand: NIWA.

Rutherford, K., & Cox, T. (2009). Nutrient trading to improve and preserve water quality. *Water and Atmosphere, 17*(1). 12-13.

Salmon, G., & Joy, M. (2011,). 100% Pure? *Fish & Game New Zealand, 33,* 8-15.

Salmon, P. (2007). *Revisiting the Purpose and Approach to Resource Management*. Paper presented at the Beyond the RMA Conference.

Scarsbrook, M. (2011a). *Best Practice Dairying Catchments- What worked, what didn't and where to from here?* In L. Currie & C. Christensen (Eds.), *Adding to the knowledge base for the nutrient manager* (Occasional Report No. 24). Palmerston North, New Zealand: Fertiliser and Lime Research Centre, Massey University.

Scarsbrook, M. (2011b, April). Nutrient losses 'one of our greatest challenges. *Dairy Insight*, 6-7. Retrieved from DairyNZ's Dairy Insight files: http://www.dairynz.co.nz/file/fileid/35616

Schindler, D., & Vallentyne, J. (2008). *The Algal Bowl: Overfertilization of the worlds freshwater and estuaries*. Alberta, Canada: The University of Alberta Press.

Semadeni-Davies, A., Elliott, S., & Shankar, U. (2011). *The CLUES Project: Tutorial Manual for CLUES 3.1* (NIWA Client Report No. HAM2011-003), Prepared for Ministry of Agriculture and Forestry. Retrieved from NIWA ftp website: ftp://ftp.niwa.co.nz/clues/CLUES%20Manual%20v3.1_21%20March%202011.pdf

Smith, C., Wilcock, R., Vant, W., Smith, D., & Cooper, A. (1993). *Towards Sustainable Agriculture: Freshwater quality in New Zealand and the influence of agriculture* (MAF Policy Technical Paper 93/10). Report prepared for Ministry of Agriculture and Fisheries and Ministry for the Environment. New Zealand: Ministry of Agriculture and Fisheries.

Smith, R., Lowe, D., & Wright, I. (n.d.). *Volcanoes*. Retrieved from http://www.teara.govt.nz/

Smith, V. H., Tilman, G. D., & Nekola, J. C. (1999). Eutrophication: impacts of excess nutrient inputs on freshwater, marine, and terrestrial ecosystems. *Environmental Pollution, 100*, 179-196.

Smith, W., & Montgomery, H. (2004). Revolution or evolution? New Zealand agriculture since 1984. *GeoJournal, 59*(2), 107-118.

Statistics New Zealand. (2009). *Global New Zealand – International Trade, Investment, and Travel Profile: For the year ended June 2009*. Retrieved from the Statistics New Zealand website: http://www.stats.govt.nz/browse_for_stats/industry_sectors/imports_and_exports/global-nz-jun-09.aspx:

Statistics New Zealand (Producer). (2010, May 13). *Big increase in South Island dairy cattle numbers* [Press Release]*:* Retrieved from http://www.stats.govt.nz/browse_for_stats/industry_sectors/agriculture-horticulture-forestry/AgriculturalProduction_MRJun09final.aspx

Statistics New Zealand. (2011). *Global New Zealand-International trade, investment, and travel profile: Year ended June 2011*. Retrieved from the Statistics New Zealand website: http://www.stats.govt.nz/browse_for_stats/industry_sectors/imports_and_exports/global-nz-jun-11/key-points.aspx

Stevenson, M., Wilks, T., & Hayward, S. (2010). *An overview of the state and trends in water quality of Canterbury's rivers and streams* (Report No. R10/117). Christchurch, New Zealand: Environment Canterbury.

Taylor, R., & Smith, I. (1997). *The State of New Zealand's Environment 1997*. Retrieved from the Ministry for the Environment website: http://www.mfe.govt.nz/publications/ser/ser1997/index.html

Tchobanoglous, G., & Schroeder, E. D. (1987). *Water Quality: Characteristics Modelling Modification*. Reading, Massachusetts: Addison-Wesley Publishing Company.

Te Runanga o Ngai Tahu. (1999). *Te Runanga o Ngai Tahu Freshwater Policy*. Retrieved from Te Runanga o Ngai Tahu website: http://www.ngaitahu.iwi.nz/Ngai-Tahu-Whanui/Natural-Environment/Environmental-Policy-Planning/Freshwater-Policy.php

Thomas, C., & Tracey, D. (2005, January). Nitrogen and Phosphorus Cycles. *River Science: The science behind the Swann-Canning River Clean-up program*, 4, 1-4, Retrieved from http://www.swanrivertrust.wa.gov.au/science/river/Documents/River%20Science%20Issue%2004%20Nitrogen%20and%20phosphorus%20cycles.pdf

Thornton, S., Paul, S., & Kerr, G. (2001). *Our clean green image: What's it worth?* (Ref. ME 405). Prepared for the Ministry for the Environment. Wellington, New Zealand:PA Consulting Group

Tourism New Zealand. (2009). *Pure As - 10 years of 100% Pure New Zealand*. Retrieved from the Tourism New Zealand website: http://www.tourismnewzealand.com/media/106877/10%20year%20anniversary%20of%20100%20%20pure%20new%20zealand%20campaign%20-%20pure%20as%20magazine.pdf

University of Waikato. (2011). *Rotorua Caldera Formation*. Retrieved from http://www.sciencelearn.org.nz/

Verburg, P. (2009). *Nutrient status in Lake Brunner and effects of nutrient loading* (NIWA Client Report: HAM2009-137) Prepared for West Coast Regional Council. Hamilton, New Zealand: NIWA.

Verburg, P., Hamill, K., Unwin, M., & Abell, J. (2010). *Lake water quality in New Zealand 2010: Status and trends* (NIWA Client Report: HAM2010-107). Prepared for Ministry for the Environment. Hamilton, New Zealand: NIWA.

Vincent, W. F., Gibbs, M. M., & Dryden, S. J. (1984). Accelerated eutrophication in a New Zealand lake: Lake Rotoiti, central North Island. *New Zealand Journal of Marine and Freshwater Research, 18*(4), 431-440.

Waikato Farm Environment Award Trust. (2002). *Introducing nutrient budgets* [informative pamphlet]. Hamilton, New Zealand: Environment Waikato.

Wainwright, J., & Mulligan, M. (Eds.). (2004). *Environmental modelling: finding simplicity in complexity.* West Sussex, England: Wiley

Van Spanning, R., Delgado, M., & Richardson, D. (2006). The Nitrogen Cycle: Denitrification and its relationship to N_2 fixation. In D. Werner, & W. Newton (Eds.) *Nitrogen fixation in agriculture, forestry, ecology and the environment* (pp. 277-342). Netherlands:Springer Verlag.

West Coast Regional Council. (2008). *Groundwater Nutrient Movement: Inchbonnie Catchment* (Technical Report 08003). Greymouth, New Zealand: West Coast Regional Council.

West Coast Regional Council. (2010). Proposed Regional Land and Water Plan. Retrieved from West Coast Regional Council website: http://www.wcrc.govt.nz/plans/rma_plans/land_water.htm

Westland Milk Products. (2010). *From our land to yours: Annual Report 2010*. Retrieved from http://westland.co.nz/sites/westland.co.nz/files/u6/WestlandCo-opDairy-AR2010.pdf

Westland Milk Products. (2011). *Environmental Code of Practice*. Hokitika, New Zealand: Westland Milk Products.

Wheeler, D., Ledgard, S., De Klein, C., Monaghan, R., Carey, P., McDowell, R., et al. (2003). OVERSEER Nutrient Budgets- moving towards on-farm resource accounting. *Proceedings of the New Zealand Grassland Association, 65*, 191-194.

White, P., Hong, T., Zemansky, G., McIntosh, J., Gordon, D., & Dell, P. (2007). *Groundwater and Surface Water Hydrology in the Lake Rotorua Catchment, New Zealand, and Community Involvement with Lake Water Quality Restoration*. Paper presented at the Korean Water Resources Association, Korea. Retrieved from http://www.hydrologynz.org.nz/documents/White_KWRA_Paper.pdf

White, T., & Wilson, J. (2007). *Information transfer on dairy farms in five New Zealand regions*. Prepared for Dairy Insight. Mosgiel, New Zealand: AgResearch.

Wilcock, R., & Duncan, M. (2009). *Inchbonnie (Lake Brunner) Catchment Study* [Summary presented to farmers]. Retrieved from http://maxa.maf.govt.nz/sff/about-projects/search/06-064/summary-for-farmers.pdf

Wilcock, R., Monaghan, R. M., Thorrold, B. S., Meredith, A. S., Betteridge, K., & Duncan, M. J. (2007). Land-water interactions in five contrasting dairy catchments: issues and solutions. *Land and Water Resources Research, 7*, 2.1-2.10.

Wilcock, R. J., Nagels, J. W., Rodda, H. J. E., O'Connor, M. B., Thorrold, B. S., & Barnett, J. W. (1999). Water quality of a lowland stream in a New Zealand dairy farming catchment. *New Zealand Journal of Marine and Freshwater Research, 33*, 683-696.

Williams. (2006). Resource management and Maori attitudes to water in southern New Zealand. *New Zealand Geographer, 62*, 73-80.

Woods, R., Bidwell, V., Clothier, B., Elliott, S., Harris, S., Hewitt, A., et al. (2006). *The CLUES project: Predicting the effects of landuse on water quality-stage II* (NIWA Client Report: CHC2006-096). Prepared for Ministry of Agriculture and Forestry. Christchurch, New Zealand: NIWA.

Woods, R., Elliott, S., Shankar, U., Schmidt, J., Bidwell, V., Bright, J., et al. (2004). *The CLUES project: Predicting the effects of landuse on water quality-stage I*. (NIWA Client Report: CHC2004-097). Prepared for Ministry of Agriculture and Forestry. Christchurch, New Zealand: NIWA.

World dairy situation (2010, June) *Milk & Juice.* Retrieved from http://www.mjmagazine.co.za/acrobat/jun_11/Dairy_world_M%26J%20JUN%2011.pdf

World Dairy summit in NZ with 2200 participants from 66 countries. (2010, November 8). *MercoPress South Atlantic News Agency*.

Yerex, S. (2009). *Protecting Lake Taupo: The strategy and the lessons*. Retrieved from Lake Taupo Protection Trust website: http://www.laketaupoprotectiontrust.org.nz/file/project-review/protecting-lake-taupo_the-strategy-and-the-lessons.pdf

$51,000 in fines for dirty dairying. (2012). *The New Zealand Herald*. Retrieved from http://www.nzherald.co.nz

Appendix 1 Telephone interview transcript

Hello, My name is Nicola McHaffie, I am the University of Canterbury student doing a project in the Inchbonnie (or Waikakahi) catchment with DairyNZ. You should have received a letter in the mail recently from us about the development of farm benchmark targets and nutrient management for your catchment?

No what was the letter about?

The letter was a brief explanation of the best practice dairying catchment project update meeting that was held recently. It also mentioned the upcoming workshop with Inchbonnie (or Waikakahi) farmers to look at proposed benchmarks. It was sent out by Shirley Hayward and Jessie Chan from DairyNZ

I am doing a short survey with farmers in the catchment about their initial thoughts on this benchmarking initiative. Are you the right person to talk to about this? It takes about fifteen minutes, is this a good time to talk about it or should I call you back later in the day?

I would like to start with some questions that describe you and your farming situation

1. **What is the size of your dairy farm?**
   Milking platform: _________ effective hectares
   Run-off: _________effective hectares
2. **How many years have you farmed this region?**
3. **What best describes your position on the farm?**
   Farm owner/operator   Investing Equity Partner   Managing Equity Partner
   Sharemilker   Farm Manager   Other :___________
4. **Overall, how many years have you been involved in dairy farming?**

These next questions ask about your understanding and views of nutrient management

5. **Do you have a nutrient budget or nutrient management plan for your farm?**
6. **Over the last year how often have you referred to your budget/plan?**
7. **How do you use the nutrient budget or nutrient management plan for your farm?**
   - Do you know how much P or N is lost per hectare?
   - Do you know what your P loss risk is?
8. **On a scale of 1-5 where 5 is very useful and 1 is not useful at all how useful is your budget/management plan to you on-farm?**
9. **In your opinion what do you think efficient nutrient use involves?**
10. **On a scale of 1-5 where 5 is very efficiently and 1 is not efficiently at all. In your opinion how efficiently are you using your nutrients on farm? This includes all inputs sources such as fertilisers, effluent, feed supplements?**

These next questions ask you about your understanding and views of nutrient benchmarks

What I mean by a benchmark is...a number that could be included in your nutrient management plan. It would be developed using values from the farms in your region. It could be to do with: N conversion efficiency which is how efficiently your farm converts external N inputs (such as feed) into N contained in product (milk), N leaching loss which is the amount of nitrogen leached and lost from the farm from soil and drainage water below the plant root system, Or P runoff which is an estimation of the amount of P lost from the farm via surface runoff. The benchmark is designed to be a sort of stick in the sand or an achievable nutrient management target to work towards. It is what good looks like in your region.

11. **Using the same 1-5 scale as before where 5 is very useful and 1 is not useful at all How useful would it be to you to have a benchmark that indicated a target for efficient nutrient use?**
    - **Why have you given it this rating?**
12. **Using the same 1-5 scale as before where 5 is very useful and 1 is not useful at all How useful would it be to you to have a benchmark that indicated an N loss or P loss target?**
    - **Why have you given it this rating?**
13. **What would drive you to achieve or meet these benchmarks?**
14. **Do you think the introduction of benchmarks will result in you doing anything differently on-farm?**
    - **What would you do differently?**

Thank you for taking the time to do this survey. Your input will be of great help to my research. Any information provided in the survey will remain anonymous in the final publication with names and personal information excluded however if you would like to remove your involvement at any time that is fine my number is 0220365453

If you have any further questions or would like to talk a DairyNZ person Jessie Chan's number is: (03) 3020060 or my University supervisor Eric Pawson on (03) 364 2987 ext. 6930. Alternatively you can contact me, Nicola, on 0220365453